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Artifact-based reflective interviews for identifying pragmatic epistemological resources

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ARTIFACT-BASED REFLECTIVE INTERVIEWS FOR IDENTIFYING PRAGMATIC EPISTEMOLOGICAL RESOURCES

BY

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

ARTIFACT-BASED REFLECTIVE INTERVIEWS FOR IDENTIFYING PRAGMATIC EPISTEMOLOGICAL RESOURCES

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Physics Education Research studies the science of teaching and learning physics. The process of student learning is complex, and the factors that affect it are numerous. Describing students' understanding of physics knowledge and reasoning is the basis for much productive research; however, such research fails to account for certain types of student learning difficulties. In this dissertation, I explore one source of student difficulty: personal epistemology, students' ideas about knowledge and knowing.

Epistemology traditionally answers three questions: What is knowledge? How is knowledge created? And, how do we know what we know? An individual's responses to these questions can affect learning in terms of how they approach tasks involving the construction and application of knowledge. The key issue addressed in this dissertation is the effect of methodological choices on the validity and reliability of claims concerning personal epistemology. My central concern is contextual validity, how what is said about one's epistemology is not identical to how one behaves epistemologically. In response to these issues, I present here a new methodology for research on student epistemology:

video artifact-based reflective interview protocols. These protocols begin with video taping students in their natural classroom activities, and then asking the participants epistemological questions immediately after watching selected scenes from their activity, contextually anchoring them in their actual learning experience.

The data from these interviews is viewed in the framework of Epistemological Resource Theory, a framework of small bits of knowledge whose coordination in a given context is used to describe personal epistemology. I claim that the privileged data from these interviews allows detailed epistemological resources to be identified, and that these resources can provide greater insight into how student epistemologies are applied in learning activities.

This research, situated within an algebra-based physics for life scientists course reform project, focuses on student work in Modeling Informed Instruction (MII) laboratory activities, which are an adaptation of Modeling Instruction. The development of these activities is based on the epistemological foundations of Modeling Instruction, and these foundations are used to describe a potential assessment for the epistemological effectiveness of a curriculum.

INTRODUCTION

What is Physics Education Research?

To put it concisely, Physics Education Research (PER) is the scientific study of the teaching and learning of physics. As a strongly interdisciplinary research field, PER concerns itself with the broad spectrum of all that may or may not affect learning physics, and seeks to understand this spectrum through scientific investigations ranging from functional Magnetic Resonance Imaging (fMRI) of blood flow in the brain (Dunbar, 2009) to qualitative studies of the social dynamics of learning communities (Brewe, Kramer, & O'Brien, 2009; Otero, 2004), and everything in between. Historically, PER began in the classroom, focusing on identifying student difficulties with particular content, and devising curricula to help students overcome these difficulties effectively (McDermott & Shaffer, 1992; Schaffer & McDermott, 1992). As the field grew, it broadened beyond this phenomenological approach, and engaged with the literature on cognition. The majority of the work done in PER today integrates cognitive theory with improving student learning, going so far as to look into how one's theoretical perspective affects the resulting classroom reform (Scherr, 2007). Through the myriad studies PER undertakes, it has developed and adapted theories of learning that support a vast spectrum of inquiry, while attempting to maintain a connection to improving the learning of physics inside and outside of the traditional classroom (Mayhew & Finkelstein, 2009; Bartley, Mayhew, & Finkelstein, 2009).

At the tiniest end of the spectrum, where PER primarily utilizes results from other fields, there are neurobiological theories that describe the coordination and activation of neurons in the brain (Fuster, 1999). These theories help shape our ideas about cognition, which leads to cognitive theories that concern themselves with the content that is taught in physics courses and how it is learned (Posner, Strike, Hewson, & Gertzog, 1982; diSessa, 1993; Hestenes, Wells, & Swackhamer, 1992). When cognitive models showed themselves to be missing parts of the picture, metacognitive theories that discuss the learning skills subjects may or may not utilize in their efforts to learn were added to the mix (Kung & Linder, 2007). Epistemological theories that describe ideas about knowledge itself, that students maintain in general and in domain-specific areas delve even deeper beyond the traditional content of physics courses (Hofer & Pintrich, 2002). There are behavioral theories that explain the interactions of learners and their environment, giving insight into the role classroom culture plays in learning (Otero, 2004). There are curriculum development theories that guide our development of reformed materials based on our findings (McDermott & Shaffer, 1992; Schaffer & McDermott, 1992). There are even theories about theories, or theoretical frameworks (Redish, 2003), whose objective it is to help us keep track of all the different ways we model learning and how they relate to each other so that we can ultimately apply our collective understanding towards our fundamental goal: to improve the teaching and learning of the science of physics.

In this dissertation I will attempt to guide us on a journey through an instruction reform project that illuminates a scientific approach to understanding a single aspect of learning physics out of the vast landscape touched upon above. The project has two major stages, the first of which involves re-writing the lab sequence for an algebra-based introductory physics course for life science students by adapting a successful pedagogy already developed and deployed by the PER community, Modeling Instruction. The second stage is the design and application of a qualitative methodology to investigate how students engage with these reformed lab activities, specifically how their actions in the laboratory reflect their ideas about scientific knowledge and the role these activities play in learning science. This journey involves significant curriculum and instruction development, theoretical analysis and discrimination, methodological progression, and illustrative data analysis and interpretation.

CHAPTER I

ANATOMY OF THIS RESEARCH

In this chapter I will outline the entirety of my dissertation research project. Each of the core ideas presented in this chapter will be expanded on in subsequent chapters.

PHYS 401/402: Introduction to Physics Course Reform Project

The Course

This research is set within the context of a NSF funded course reform project which targets PHYS 401/402: Introduction to Physics, the College of Life Sciences and Agriculture (COLSA) service course (a required course for most COLSA majors), at the University of New Hampshire (UNH). This course is both the only Introductory Physics for the Life Sciences (IPLS) and the only algebra-based introductory physics course offering at UNH. The overarching course reform is motivated by the dual needs of the PHYS 401/402 student population, physics that is relevant to careers and further education in the life sciences as well as physics that is mathematically supported at the algebra level.

Physics 401/402 is taught in a consecutive Fall and Spring term at UNH with an enrollment of approximately 300 students. As mentioned above, 85% of these students are registered in COLSA. The students have a varied physics background, with 25% having taken no prior physics, 20% having had conceptual physics, and the majority of the remaining having taken college prep physics. Their experience in mathematics is slightly more uniform, with 95% having algebra preparation, 65% having taken trigonometry, and over 75% having had some experience with calculus. In terms of class standing, there are nearly no first-year students, with about two-thirds being upper classmen, and the remaining third being sophomores. Finally, nearly 85% of the students in this course report that it is a requirement for their major.

The course is made up of two lecture sections which each meet for fifty minutes, three times per week. The course is also made up of twelve lab sections, which meet once per week for an hour and fifty minutes, with students coming from both lecture sections (except for the lab sections that have scheduling conflicts with a lecture section). The course schedule does not include recitations, as many introductory physics courses do, for targeted problem solving work. Two efforts are made to fill this gap: the first is the addition of a "group work" component to the course, and the second is the conversion of several weeks of lab into group problem solving sessions. The "group work" component of the course is a weekly undertaking throughout the semester with three options: increased individual problem solving homework, which is essentially more problem solving practice with no explicit support structure; self-organized study groups, which are small groups that work together throughout the semester and check in with the professor at regular intervals; and Peer Led Team Learning (PLTL), where students work in small groups on problems with a successful PHYS 401/402 student from a previous year as their coach (Gosser, Cracolice, Kampmeier, & Roth, 2001). The converted laboratory sessions are run with the same Teaching Assistants as the regular lab sections and students work on problems in their regular lab groups.

Three Emphases of Reform

The project to reform PHYS 401/402 at UNH has three major emphases to it: embedded biologically relevant material and applications, to motivate and improve student engagement; consistent and rigorous treatment of the mathematics used, specifically focusing on the meaning of mathematical relationships; and explicit attention to scientific epistemology, how students view and approach scientific knowledge developed in an academic setting. To address these three emphases, we chose to adapt Modeling Instruction to our course context. The adaptation focuses on the fundamental structure of the Modeling Cycle, a process for developing and deploying scientific models, while working within our institutional constraints (Wells, Hestenes, & Swackhamer, 1995).

The choice of Modeling Instruction is apt because it either already addresses, or is easily adapted to address each of our project's emphases. Modeling Instruction focuses on student development of coherent scientific models, simplified descriptions of a system or behavior that encompass some essential aspect(s) of the phenomenon. While developed for physics instruction, this pedagogy is authentic for all sciences. For instance, while many of the standard physics models are well suited for an IPLS course, I also developed activities that lead students through the process of developing models of natural phenomena that are directly applicable to biological systems. Modeling Instruction also follows an empirical approach, where students design aspects of their experiment, collect data, construct representations of their data, and interpret these representations to develop a coherent model of the data for themselves. This approach requires students to understand the mathematical treatments of the data that they perform in generating and interpreting their representations. Finally, and the core of this dissertation, Modeling Instruction is built upon a well-articulated scientific epistemology. The Modeling Cycle itself is designed to carry students through the process of authentic scientific inquiry, which requires productive mindsets and approaches to learning activities for optimal gains in understanding of content, procedure, and philosophy.

The Major Players

To tackle this project I worked with a team of four other investigators, each acting as the primary expert in one core component of our reform (although contributing to all components): Dr. Dawn C. Meredith, principal physicist; Dr. Jessica Bolker, principal biologist; Dr. Gertrud Kraut, principal mathematician; Dr. Jamie Vesenka, principal modeling instructor. And, as a result of this research project I have developed into the principal epistemologist. Within the project the major responsibilities broke down as follows: Dr. Meredith, lead lecturer, responsible for physics content in lecture and problem solving materials; Dr. Bolker, co-lecturer, responsible for biological content coordination in lecture and problem solving materials; Dr. Kraut, responsible for analysis of mathematics learning issues; Dr. Vesenka, responsible for consulting and training teaching assistants in Modeling Instruction; and myself, responsible for the design and deployment of model development laboratory activities, and analysis of student epistemologies within those activities. In the following manuscript I will describe my work in the development of model development laboratory activities, a methodology for accessing student epistemologies in these activities through reflective interviews, and the analysis of these reflective interviews.

Modeling Informed Instruction

Modeling Instruction and the Modeling Cycle

By choosing Modeling Instruction as the starting point for the reform of PHYS 401/402 we made a commitment to the underlying pedagogical structure of Modeling Instruction, teaching a set of core scientific models that are created and applied by following the Modeling Cycle, Figure 1-1 (Wells, Hestenes, & Swackhamer, 1995). The Modeling Cycle is broken down into two stages, Model Development and Model Deployment, each with their own phases. In our adaptation of Modeling Instruction we made the decision to use the majority of our course's laboratory meetings for all of our student-centered Model Development activities (some models were developed in interactive lecture demonstrations), and to use the remaining lecture and laboratory meetings for Model Deployment activities.

In Model Development activities students engage in the first stage of the Modeling Cycle, creating a model of a natural phenomenon through an empirical investigation devised with their critical input. The model development activities written for PHYS 401/402 at UNH are referred to as Modeling Informed Instruction (MII), and follow the adapted structure seen in Figure 1-2; this structure will be discussed further in Chapter 2. The rest of this research is concerned with these activities, specifically how students engage in the design, undertaking, and analysis of experiments to create scientific models of natural phenomena.

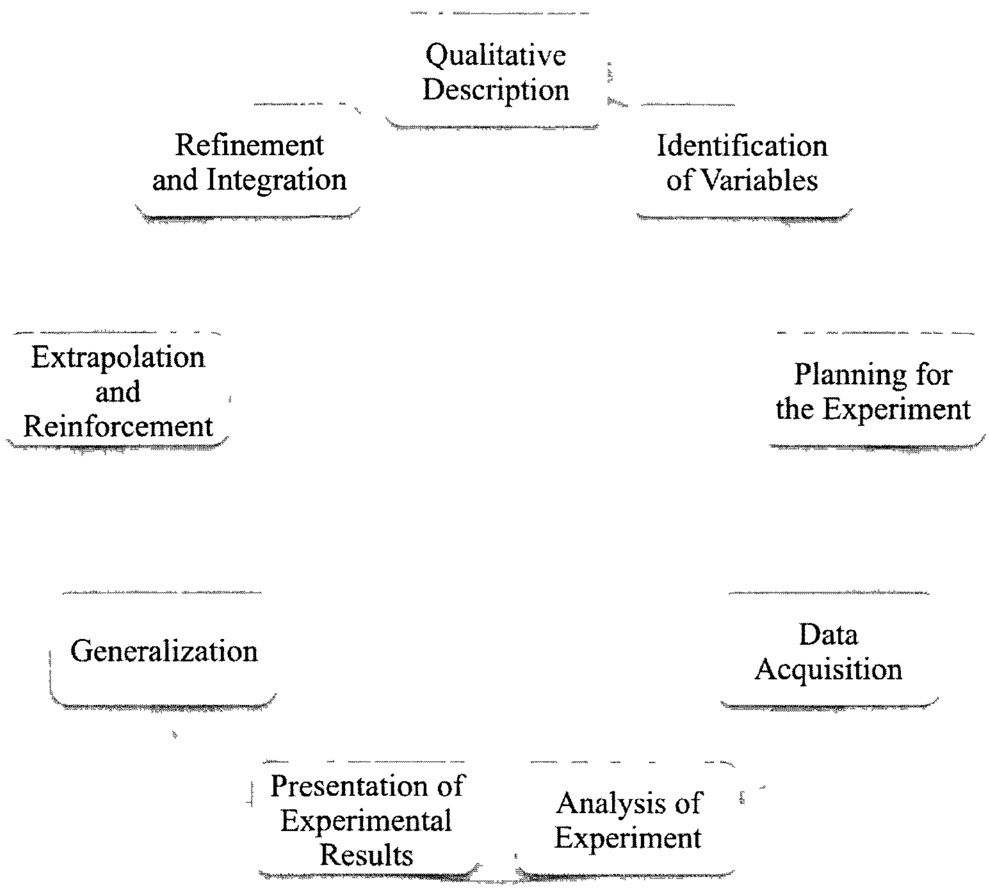

Figure 1-1: The Modeling Cycle. The two phases combined into a single cycle of nine stages.

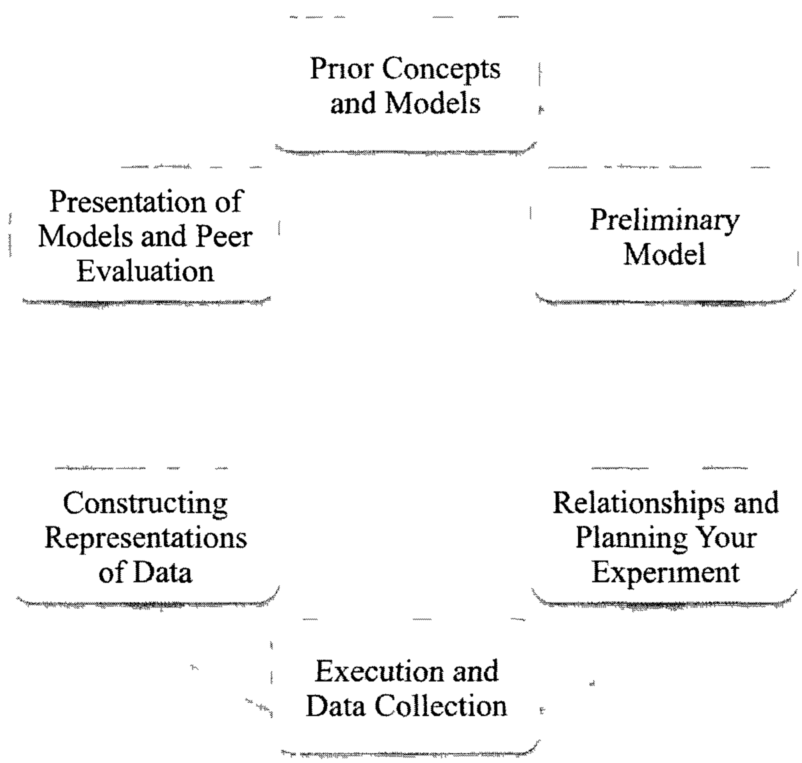

Figure 1-2: The MII Model Development Cycle. All of these phases are executed in each MII Model Development Activity.

A Case for Pragmatic Epistemology

Epistemology or Not?

Epistemology is defined as the study of knowledge and knowing; however, as I will discuss throughout this work, the evidence for how epistemology may affect teaching and learning requires either a more open definition that includes ideas about learning as well, or perhaps a new "ology" to be defined. In this section, I will briefly discuss traditional epistemology. Then, I will reduce the scope of epistemology to scientific epistemology as a more appropriate scope that is applicable to this study. Next, I will narrow my focus further to an individual for the context of this research, and situate this work within the current epistemological PER landscape. Finally, this will allow me to present my research questions in more precise terms, and motivate the quest to answer them.

Clarifying Epistemology

Epistemology, the study of knowledge and knowing, concerns itself with three fundamental questions: (1) What is knowledge? (2) How is knowledge created? and (3) How do we know what we know? Immediately, we might consider the second and third questions directly targeting the notion of learning, which I will discuss later. With regards to the first question, traditional epistemology's core concern is propositional knowledge, as opposed to process knowledge, knowing how, or acquaintance knowledge, knowing whom. The most thoroughly discussed definition of propositional knowledge in response to the first question is that knowledge is a true, justified, belief (Scheffler, 1978). Each of these three characteristics of knowledge is then considered an independent issue: (a) What is truth? (b) What counts as justification? (c) What is considered a belief? For science education research, addressing these three characteristics, as well as the second and third questions, can benefit by reducing our concentration from traditional epistemology to the subset of scientific epistemology.

By reduction to scientific epistemology, ideas about knowledge and knowing that deal only with knowledge created through authentic scientific endeavors, we are able to look at the three major questions above as targeting the scientific enterprise. To be explicit: the truth condition for scientific knowledge in the modern age falls under the post-positivist jurisdiction that states that scientific knowledge must be falsifiable, but can not be proven true; the justification for scientific knowledge must derive from empirical evidence; and scientific knowledge is unlikely to be believed unless its justification is replicable. For the purposes of science education research, each of these questions opens a key line of inquiry about student learning and understanding of the scientific enterprise. For example, traditional lab instruction emphasizes confirmation of "known" laws, which may create confirmation bias in student results and foster the development of an errant positivist scientific philosophy in students. For my research, focusing on individual students further restricts the discussion of epistemology to personal scientific epistemology.

Investigating personal epistemology constrains as well as broadens the discussion by focusing on the epistemology held by individuals (Hofer & Pintrich, 2002). Personal scientific epistemologies ought be describable within the context of scientific epistemology discourse, a constraint; however, investigating personal scientific epistemologies may also show that an individual's understanding of science and the scientific enterprise is not what the scientific community would consider appropriate, or productive scientific epistemology, a broadening (Adams, Perkins, Podolefsky, Dubson, Finkelstein, & Wieman, 2006) (Redish, Sal, & Steinberg, Student expectations in introductory physics, 1998) (Elby & Hammer, 2001). In Figure 1-3 I illustrate how a sophisticated scientific epistemology is the regulative ideal held by the community of scientists (dark circle), while describing personal scientific epistemology must include ideas that do not belong to this ideal (light circle).

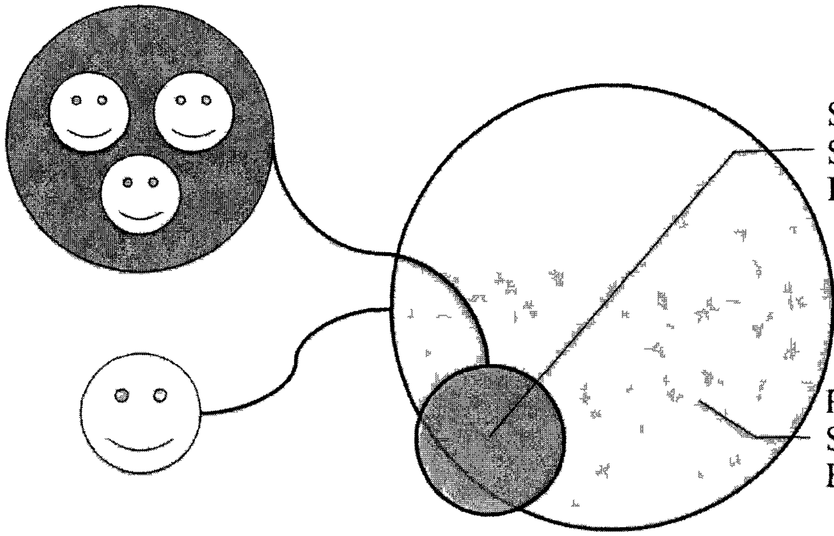

Figure 1-3 Personal Epistemology includes ideas not considered part of a sophisticated scientific epistemology while the community of practitioners owns the sophisticated scientific epistemology

With the personal scientific epistemological perspective in hand we can now make the final fine tunings to the orientation of this research. As a physics education research undertaking, the goal of this research is to understand the ways in which students actually work within the confines of our classrooms on the activities that we design and construct to aid in their learning of authentic physical science. Because of this critical focus on the student engagement of activities as they are used in the classroom, I make a final crucial adjustment to my theoretical perspective. I focus on developing a description of the personal scientific epistemologies that students bring to bear during their engagement with the MII activities, as authentic scientific inquiry learning activities, that I will refer to as "pragmatic epistemology" (Sandoval, 2005). By defining the scope of pragmatic epistemology in this way, I am open to describing ideas about learning as well as ideas about knowledge and knowing, while constraining the target learning activities to the authentic scientific inquiry based MII model development activities. In order to engage in this study of pragmatic epistemology, I must make explicit my theoretical perspective for modeling a personal epistemology (Hofer & Pintrich, 2002).

Resources as a Theoretical Perspective

Within the PER community there has been a transition in the modeling of cognitive structures that parallels that of cognitive science (Hestenes D. , 1992). This transition is most clearly exemplified by the transition in physics content studies from misconception based to resources (knowledge in pieces) based (Scherr, 2007). Many studies fall under misconceptions research, which identifies large-scale coherent naive conceptual structures which students reason with by default, and develops curricula based on conceptual change theory that elicit, confront, and replace these misconceptions (Posner, Strike, Hewson, & Gertzog, 1982). The second part of this process: elicit, confront, replace; usually has students work through a sequence of physical situations for which their conceptions at first work, elicit, then fail, confront, then are corrected to the accepted conceptions which work in the situations where their misconceptions failed. Resources research on the other hand identifies smaller-scale productive conceptual notions and develops curricula to help reorganize these into the productive target conceptual structures. As opposed to the elicit, confront, replace model, the curricula often utilize explicit contrasting activities that emphasize different activations of small conceptual ideas, not large-coherent structures (Redish, 2003), (Sayre, 2007), (Scherr, 2007), (Hammer & Elby, 2003). The major divergence of these two theoretical perspectives is that resource theory focuses on smaller productive conceptual notions in order to describe the complex context dependence of student reasoning, while misconceptions theory focuses on well structured beliefs or theories that can be replaced wholesale, assuming consistent application of both the misconception and correct conception across various contexts (Wittmann, 2006), (Sayre, 2007), (Scherr, 2007). As will be discussed throughout this dissertation, I chose to structure my inquiry based on the resources perspective, as applied to epistemology (Hammer & Elby, On the Form of a Personal Epistemology, 2002).

Differentiating Among PER Epistemological Research

As I have defined my interest in the previous sections, describing personal student epistemology as it is applied in reformed model development activities in a resources framework, I would like to clarify this goal in terms of existing PER epistemological research.

Across the PER epistemology research community there are a few major paradigms: epistemic beliefs determined through surveys, epistemic frames defined through observation, and epistemological resources identified through interviews and observation. I will briefly explain each of these paradigms and differentiate them from my work. A few key ideas for comparing these paradigms are validity and reliability, epistemological form, and methodological implications. Here I will focus on the first two, as the latter two are addressed in the ensuing chapters. Validity as I will discuss it in this work comes in two major flavors: contextual, does the data come from authentic classroom learning activities or research interventions; and interpretive, would the participant agree with the interpretation or is the interpretation the researcher's construction. Reliability also comes in two flavors: methodological, given the same student activity, could another researcher achieve similar data; and analytical, given the same data, would another researcher provide a similar interpretation.

Within PER there are at least four significant surveys that have epistemological indicators: Epistemological Beliefs Assessment for Physical Sciences (EBAPS), Maryland Physics Expectations survey (MPEX) (Redish, Sal, & Steinberg, 1998), Views About Science Survey (VASS) (Halloun & Hestenes, 1998), and Colorado Learning Attitudes about Science Survey (C-LASS) (Adams, Perkins, Podolefsky, Dubson, Finkelstein, & Wieman, 2006). As surveys, each of these instruments has weak claims of contextual validity, they do not assess students in their actual classroom activities; however, the interpretive validity, methodological reliability, and analytical reliability claims are strong. The clearest example for these claims is the C-LASS. To address interpretive validity, the development of the C-LASS involved iterative interviews. As a survey the methodological reliability is built into the lack of researcher involvement in data collection, and the analytical reliability is controlled in a similar fashion, with a provided statistical analysis package. While this survey clearly addresses three of the issues I brought up quite well, the final issue, contextual validity, remains significant as studies have shown that what participants self-report is different from how they act (Louca, Elby, Hammer, & Kagey, 2004).

Epistemological framing is a theoretical construct that PER has adapted from sociolinguistics and discourse analysis (Tannen, 1993). Frames are what might be answered to the question “what’s going on here?” and are applied through observational protocols which focus on behavioral clusters. Because these protocols are applied to actual classroom activities, they are contextually valid; however, the missing interaction between the researchers and participants means that the frames identified by the researchers may not agree with what the students believe they are doing. A further concern is that by being based entirely on observation of behavioral clusters, framing research may not in fact penetrate the sphere of personal epistemology. In fact, an open question regarding frames is whether or not the participants' personal epistemologies align with the group epistemological frame, although it is clear that their outward behavior indicates that this is true (Scherr & Hammer, 2009). In terms of reliability, frames research has been shown to be highly methodologically and analytically reliable (Scherr R. E., 2009).

Epistemological resources round out the field of PER epistemological research constructs, and are the focus of this research. As adapted by Hammer from Minsky's computational model of the mind, a resource itself is a small bit of knowledge that can be applied in a context, either productively or not. The identification of epistemological resources is not as well defined as frames or the belief structures of surveys; however, a preliminary model includes possible categories of resources: sources of knowledge, forms of knowledge, stances, and so forth (Louca, Elby, Hammer, & Kagey, 2004). The proposed resources that come out of this research are of the form *knowledge as transmitted stuff, knowledge as fabricated stuff, acceptance, doubt,* and others. As defined, these resources leave a great deal to be desired in terms of specificity. For example, what are the ways in which knowledge is transmitted? What underlies a doubting stance, is it a lack of trust or justification? The epistemological resources described come from a variety of interviews and observation, which gives them variable claims to contextual and interpretive validity. The resources reported from interviews where participants respond to epistemological questions creates a set of valid resources in terms of interpretation. The reliability of current epistemological resource work is unclear.

The question of contextual validity, as well as methodological, and interpretive reliability drives my use of the resources framework. Resources as defined thus far are a wonderful theoretical tool, but there is rich, privileged, data that students themselves can provide on how they approach knowledge in our classroom activities. This research seeks to show how by following a particular interview methodology that combines both the contextual validity of observation, and the interpretive validity of interviewing; epistemological resources can evolve into a productive theoretical tool for modeling student personal scientific epistemologies. Furthermore, if this methodology can be well enough articulated and disseminated, then claims for methodological reliability can be strengthened, and claims of analytical reliability can be proposed.

Research Goals

By choosing the resources perspective I am orienting my research towards a constructive description of pragmatic epistemology that accepts the context dependence of individual behavior a premise of the research. As this research is explicitly set in the context of the MII model development activities, it is important to note that the pragmatic epistemological structures identified in this work may not be present in other classroom contexts. Beyond the classroom context, the choice of the resources perspective enhances my focus on constructive descriptions of pragmatic epistemology at a small scale. This small scale and focus on constructive descriptors increases the complexity of the overall structures identified, but simplifies the descriptors themselves.

With this understanding of pragmatic epistemological resources, I can appropriately present my original research questions as achievable targets derived from community-wide interests:

1. Community-wide interest: Coherent development of Epistemological Resources Theory for describing student epistemologies active in classroom instruction.
   Research Question: What are some common pragmatic epistemological resources that students activate while completing Modeling Informed Instruction Model Development Activities?
2. Community-wide interest: Assessment of instructional effectiveness on student engagement with and development of accepted scientific epistemologies.
   Research Question: How do the activated pragmatic epistemological resources correspond with the constructivist scientific modeling epistemology that underlies the design of the Modeling Informed Instruction Model Development Activities?

These two research questions drove the beginning of this research project; however, the road to answering these questions unveiled a third, and ultimately, central research question for this project:

3. Community-wide interest: Reliable Methods for identifying valid epistemological resources students activate during classroom instruction.
   Research Question: How can we gain access to the privileged information about student's pragmatic epistemological resources with minimal interference with the classroom environment?

In the next section, I will describe the qualitative research methodology that I designed to answer these questions by bringing to light students' privileged knowledge about their own actual behavior in classroom activities. This privileged knowledge is the key to moving epistemological resource theory forward by allowing researchers to define contextually and interpretively valid descriptors. Due to this third research question taking over as the central theme of my research, the work presented here gives only an initial set of findings for answering question (1) and a proof of concept for creating an epistemological assessment as targeted in question (2).

Designing a Methodology to Answer a Question

How Questions Inform Methodological Design

The two research questions that frame this project require special attention to the methodology that seeks to answer them. The first question requires a catalog of pragmatic epistemological resources as a sufficient result, and the choices made in the process of constructing these resources have great consequences for the result itself. The second question can only be answered after the first is treated sufficiently, and relies entirely on the validity and reliability of the catalog. Therefore, understanding the interplay of the researcher, methodology, and data is essential to this research.

The goal of constructing or identifying pragmatic epistemological resources, as described in previous sections, requires a focus on fine-grained dynamics of student approaches to MII activities. Along with this scale size issue, the fact that personal epistemologies are not directly observable means that in order to describe them with any claim of interpretive validity we must involve the reflection of individuals on their own actions, and stay close to their expression. However, since personal epistemology and epistemological resources have been discussed in depth in prior research, my familiarity with this research affects my inquiry and analysis of the individual reflections, and this self-awareness must be maintained throughout the work. The most appropriate starting place for such an inquiry is the tradition of Grounded Theory.

Grounded Theory

Traditional Grounded Theory is a semi well-structured protocol of combined data acquisition and analysis. The fundamental aspect of Grounded Theory is that the descriptions that emerge from the data are kept "grounded" in the data, which is to say that the terminology used to describe the data is often paraphrased from the data itself. A second key aspect of Grounded Theory is that data selection, data collection, and data analysis should be concurrent activities. One effect of this concurrence is that as a theory emerges from the data, the researchers are able to acquire new data that targets specific aspects of the theory that seem to need more definition. Another effect of this concurrence is that the theory is constantly compared to the entire data set. This "constant comparison" tactic embeds a certain level of qualitative reliability into the actual methods of data analysis, as aspects of the theory that break down when applied across the data set are pruned, or revisited. The third and final aspect of Grounded Theory that I will discuss here is that data analysis comes in two waves: open and focused coding. Open coding is the embodiment of the "grounding," the codes applied to data during open coding are quotes or paraphrases of actual data, and are expected to refrain from interpretation. Focused coding comes as more data has been analyzed, and constant comparison is yielding reliable and general ideas that can be applied across data sources. The combination of these three core ideas of grounded theory is what makes it an appropriate starting place for my methodological development: pragmatic epistemological resources should reflect the context of their identification (grounded), pragmatic epistemological resources should be identified through and applicable to multiple data sources (constant comparison), and finally pragmatic epistemological resources should be developed through a systematic analytical approach (Schram, 2006; Charmaz, 2006).

However, as I looked to Grounded Theory to inform my methodology for this research there were obstacles in the way of a straightforward adoption. To begin with, I already had ideas about the theoretical structure of my results. I wanted to define pragmatic epistemological resources, and I had Modeling Instruction's underlying epistemology as a target structure. I also could not predict the approaches that students took to working through the MII activities, so sampling data could not be controlled. In terms of open and focused coding, I already knew what sort of codes I would apply to the epistemological design of MII activities, and from prior epistemological resources research and constructivist cognitive theory I had some preconceptions about the categorization of approaches students take to learning activities. That being said, the codes that I define come out of both the questions that I ask, which is where my ideas about personal epistemology are most explicitly affecting my results, and the students' responses to these questions. Questions such as "where did that idea come from?" prompt students to reflect on the source and acquisition of their knowledge, which inherently increases the likelihood that their responses will be coded as describing a source of knowledge or mechanism of knowledge acquisition. This effect comes most strongly into play when I discuss epistemological aspects as organizational structures of pragmatic epistemological resources in Chapter 5.

Data Acquisition Methods

On top of these issues of methodology, there were issues of methods as well. Prior epistemological research has focused on the identification of epistemological frames, games, forms, resources, beliefs, stances, and so forth, and posited these as explanations for observed difficulties in learning material. As I've mentioned, these different theoretical structures are identified through different data sources. Beliefs structures are often the results of survey based studies, and require abstract reflection by participants on their beliefs about knowledge, knowing, and learning. These studies are also analyzed in prescribed ways, as defined by the instrument's construction (Adams, Perkins, Podolefsky, Dubson, Finkelstein, & Wieman, 2006). Frames, games, forms, and stances are generally identified through observational video of classroom activity only. Due to this level of observation these theoretical structures are limited in their ability to describe personal epistemology, and although they are valid in their development upon authentic learning activity data, they are not validated by student reflection (Scherr R. E., 2009) (Scherr & Hammer, 2009) (Collins & Ferguson, 1993). Prior research on resources, and associated personal epistemological structures, such as stances, is often conducted through clinical or learning interviews, which although they allow for the interpretive validity mentioned above, they are divorced from the authentic learning activity data that the observationally based structures are founded upon.

In my attempt to solve this issue of access to student epistemology I developed a two-stage video data method along the lines of an artifact-based or stimulated recall interview (Otero & Harlow, 2009). Although such interview structures have been used to gain insight into several aspects of teaching and learning, they have not targeted student epistemology specifically (Henderson, Yerushalmi, Kuo, Heller, & Heller, 2007). This is an important distinction because the nature of epistemology is such that it is not often articulated by students directly, and stimulating artifact-based reflection on epistemology opens the doors to privileged data on student epistemology. First, students were video taped in their natural classroom setting, and then within one to two weeks of the video taping of them in class, they were invited for artifact-based reflective interviews. These interviews followed a protocol where clips from their natural classroom video were introduced and watched, and then the interviewer asked one or more questions regarding the student or group activity seen in the clip. This sequence of natural classroom video and artifact-based reflective interview was designed to ground the students in their actual classroom learning activity, while allowing for prompted-reflection and depth of epistemological interview data within a reasonable timeframe.

CHAPTER 2

MODELING INFORMED INSTRUCTION

In this chapter I will expand on the curriculum development aspect of this project. This will happen in three stages: first, I will describe Modeling Instruction and the Modeling Cycle in more detail, focusing on their epistemological underpinnings and pedagogical implications; second, I will describe the adaptation process, describing each version in the progression from the original to the fourth version of Modeling Informed Instruction and how changes were designed to maintain fidelity to Modeling Instruction and improve my adaptation; finally, I will walk through a single activity from the fourth version, and discuss the epistemological intent inherent in the design of the activity so that the grounding of the final analysis of interview data can be understood in context.

Modeling Instruction and the Modeling Cycle

Development of Modeling Instruction

Modeling Instruction (MI) was developed at the University of Arizona by the research group led by Dr. David Hestenes (Wells, Hestenes, & Swackhamer, 1995). The impetus behind the development of MI is essential to understanding why it is such a successful, extensible, and adaptable pedagogy as it has proven itself to be (Brewe E. , 2008). MI comes out of a line of inquiry driven by the parallel searches for a modeling theory of human cognition and a modeling theory of science instruction. Due to the original research's orientation towards studying science instruction as a science itself, the resulting pedagogy, Modeling Instruction, is explicitly formulated to create authentic scientific inquiry in the classroom. This pedagogy that comes out of modeling theory assumes an epistemological structure of "models," simplified representations of a phenomenon that embody the essential aspects of the phenomenon as defined by the inquiry itself. Models themselves can be coordinated into hierarchical or associative structures that can then be used to design a curriculum; however, I will explore that use in my discussion of the development of the MII activities. Modeling theory applies the model-based epistemological lens to both the theory of the mind, cognitive science, and theory of scientific knowledge. This means that I will use the same word to talk about both the mental structures that we hold on to as proxy for the natural phenomena we experience, and as a way of describing the socialized body of scientific knowledge.

Epistemology of Modeling Theory

In order to describe my understanding of Modeling Instruction upon which the MII adaptation is based, I need to further clarify the epistemology of modeling theory, which underlies Modeling Instruction. I will start with the fundamental assumption of a "natural world" that will help clarify modeling theory's two primary uses of the term "model." First, the natural world is the material world with which we interact that gives rise to our perceptions. These primary perceptions of the natural world then give rise to mental models, which are essentially subjective and reside within the individual mind. The identification of patterns in our mental models and the necessity for communicating our personal understanding with others motivates our development of conceptual models, which are essentially objective and could be said to reside within the distributed mind essential for social or societal knowledge. Conceptual models are what we might commonly refer to as concepts, which we hope are shared understandings within groups of individuals. Physical scientists are the relevant social group that "owns" the specific conceptual models we teach in physics class. Conceptual models require communication and therefore, they give rise to symbolic representations such as equations, plots, etc. These representations manifest back in the natural world in student notes, textbooks, etc., which can in turn cue mental models in individuals that correspond to the concepts encoded in the representations. The process of interacting with the natural world, building mental models, coordinating these mental models with conceptual models, applying these conceptual models to the natural world, and continuing this cycle is itself a modeling theory of learning. Figure 2-1 is a summary of this epistemological structure; however, to illustrate this dance of models I will use an example of learning about acceleration.

Assume that an individual has many experiences riding in a car and they develop a personal understanding of acceleration that is based on these experiences, this might be their current mental model. They might use this model to determine that they should lean into a turn, or use it to reason when asked about acceleration. In class they are then introduced to "acceleration," which the instructor expects them to understand as the ideal conceptual model of acceleration that the scientific community shares. The ideal conceptual model is the one that physical scientists might describe when asked, "What is acceleration?" The individual now associates this conceptual model with their separately constructed mental model, even though their mental model is almost guaranteed to be incongruent with the target conceptual model at this point. This is another way of saying that students don't come in with perfect understanding of physics simply by having grown up in a world bound by it. In the classroom and elsewhere, the conceptual model of acceleration is expressed most compactly by physical scientists as the symbol **a**, and this symbol itself finds its way back into the natural world scrawled on chalkboards, in notebooks, and in this dissertation where you read it now. The goal of defining this symbol is for it to activate a mental model that is highly coordinated with the conceptual model that the symbol is defined to represent. After more instruction, which is fundamentally a set of controlled life experiences, the individual has a shared set of experiences with their peers and with the physical science community. If these experiences constitute effective instruction, then when the individual is assessed for their "conceptual understanding" of acceleration we hope to see results that are congruent with the accepted conceptual model of acceleration. To be clear, the individual would be responding by applying their mental model that is activated by references to the conceptual model of acceleration. The holy grail of instruction is for these ideal conceptual models to be accurately reflected in the individual's mental models, and for these mental models to be activated whenever students consider these concepts, both in the classroom and in the non-academic world.

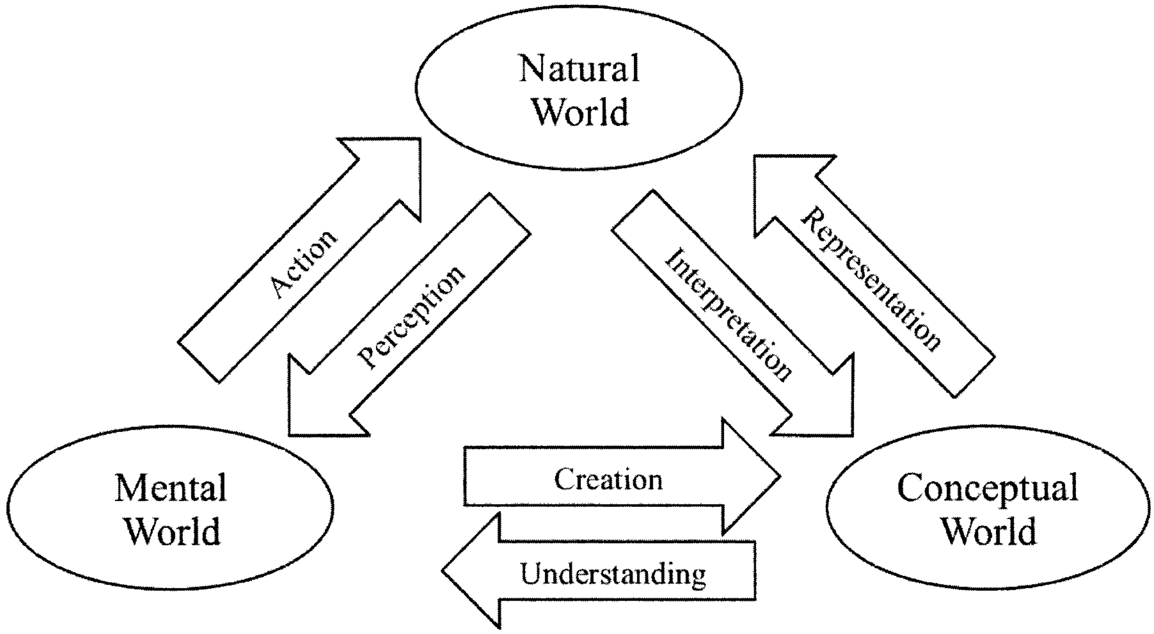

Figure 2-1: The three-world representation of a modeling epistemology. The Natural World contains all tangible things, which give rise to perception. The Mental World contains all internal mental representations, which individuals maintain. The Conceptual world contains all societal knowledge, which is shared by a group of people and persists beyond the existence of an individual.

Measuring Learning with Modeling Epistemology

By requiring an explicit awareness of our cognitive model of student knowledge, and simultaneously breaking down the curriculum for instruction into models of physical phenomena, Hestenes provided himself with a framework for measuring progress in learning. Learning objectives in this model are twofold, the set of target physical conceptual models that make up the curriculum, and the process of modeling that develops and applies these models. I will save the latter for the next section, and instead focus now on how the epistemological structure discussed so far is used to evaluate learning.

Again take the example of acceleration. A student enters class with their own mental model that is associated with the target conceptual model of acceleration, which is to say that when an instructor asks this student about "acceleration," they will respond by reasoning with their current mental model. As instruction progresses the goal is for this student's mental model to evolve towards the target conceptual model. Measuring this change is as simple an idea as measuring the closeness of their mental model to the target conceptual model at different times and evaluating the difference; however, the execution of this measurement is complex (Hestenes, Wells, & Swackhamer, 1992). Due to the epistemological structure of modeling theory, measuring the student's mental model is done by presenting the student with situations requiring the conceptual model of acceleration and evaluating whether their reasoning has brought them to a conclusion that is consistent with the target conceptual model. For Hestenes and his colleagues this ultimately resulted in the creation of the Force Concept Inventory (FCI), the first of many concept inventories which are used throughout PER to evaluate student progress in understanding sets of scientific models. The FCI covers the scientific models that span introductory mechanics (Hestenes, Wells, & Swackhamer, 1992). We can liken this development of a measurement process for learning to the invention of any other scientific measurement instrument, designed to measure a specific phenomenon, in this case student understanding, using a specific theoretical lens, in this case the modeling theory of scientific knowledge and learning.

The Modeling Cycle

In the previous sections I described how the choice of a modeling theory three-world epistemological structure, Figure 2-1, could be used to model the state of an individual's knowledge and understanding as the linkage of artifacts in the natural world to both accepted conceptual models and individual mental models. The question that remains is: how do we design instruction to stimulate progression under the modeling theory structure of scientific knowledge and learning? For this purpose, Hestenes and his colleagues developed the Modeling Cycle.

The Modeling Cycle is the core sequence of activities that is designed to engender progress from an initial association of mental models and conceptual models towards an expert mental model that closely resembles the target conceptual model. It is of the utmost importance that I make it clear that the epistemological underpinnings of modeling theories are apparent in Modeling Instruction through the explicit engagement in the Modeling Cycle. Modeling Instruction therefore, succeeds as a coordinated research-based curriculum and pedagogy. It is this intimate pairing of theoretical structure and pedagogical approach that allows Modeling Instruction to re-write the way students engage with science and to evaluate itself consistently within a coherent theoretical landscape.

The Modeling Cycle is broken down into two major stages, Model Development, and Model Deployment. The Model Development stage involves the engagement in an authentic scientific experimental inquiry to model a physical phenomenon. The Model Deployment stage involves the application of the constructed model to various scenarios involving physical phenomenon under study. Both of these stages are essential to helping an individual evolve their mental model towards the target conceptual model.

Model Development

The Model Development stage elicits and refines the student's mental model of the physical phenomenon, while associating it explicitly with the conceptual model that is the target of the unit. This stage follows a specific sequence of phases, each of which has epistemological implications. The phases in order are: qualitative description, identification of variables, planning for the experiment, data acquisition, analysis of experiment, presentation of experimental results, and generalization.

Time spent on qualitative description is intended to familiarize students with the physical phenomenon; at this point the goal is to open students' senses to everything about the physical system that they can perceive. Epistemologically this emphasizes their ownership of the model that they construct from their perceptions, and anchors their understanding in concrete experience.

Identification of variables further sharpens the focus of the model on the perceptions of the physical phenomenon by requiring definitions of measureable properties of the physical system. This is the stage at which an initial conceptual model, not necessarily the target conceptual model, is shared within the classroom, as the definitions must be agreed upon in order for measurements to be comparable. Identification of variables is also the phase in which students posit relationships between the variables they are defining. By the end of this phase each potential relationship between variables is seen as a core question driving the inquiry, and many of the remaining variables are deemed irrelevant for the model being constructed.

In the planning phase the responsibility for the inquiry is again turned to the students, as they are expected to develop their own experiment within the constraints of their apparatus. This phase further develops the connections between student's mental and conceptual models and how they translate to the physical phenomenon accessible to their senses.

The treatment of the next phase by Modeling Instruction is often overlooked as a key change to science pedagogy, because it is this data acquisition phase that many students identify as the central goal of a science lab; however, in the Modeling Cycle data acquisition is reduced to a simple step in the middle of a much larger process of authentic scientific inquiry. Much more time and effort are spent preparing for data acquisition and analyzing data than actually taking data, and students notice this discrepancy. The epistemological balancing act that must be performed at this point is to promote the importance that empirical data has for justification of scientific models, while demoting the data taking itself.

Once the data is acquired the constructing of representations takes over as the analytical approach of Modeling Instruction. Modeling Instruction is well known for its emphasis on the use of multiple representations to build student understanding of the patterns that lie within their data. The representations that most students associate with scientific understanding are equations; however, as opposed to traditional instructional methods that only require confirmation of given relationships, Modeling Instruction requires students to discover and construct their own equations through a systematic process of representation construction. The fundamental representation is the data table itself, as it organizes the data set, and gives indications of the scale over which the model will be valid. The natural progression for most students when they see a set of paired data is to plot their data pairs; this is the second representation. At this point many students are initially unaware of the difference between connecting data points with straight lines and representing the entire data set with a curve of best fit. In order to help students get over this hurdle Modeling Instruction often uses the process of linearization of the data, algebraically manipulating the variables so that the data obeys a linear relationship. However, with the computer-based data acquisition and analysis software used in the activity, it is also possible to have students evaluate several options for the relationship between the variables being plotted and to apply a curve fit in this manner. I will expand on this in the discussion of MII activities. With the curve itself on the plot students have a graphical representation of their data, which coordinates directly with the equation for their curve, or their algebraic representation. The ultimate representation is built on top of the algebraic representation, and this is the verbal interpretation of the algebraic relationship. The verbalization process for linear relationships is nearly trivial, however the physical meaning behind it based on the variables involved can be tricky. Nonlinear relationships push students to come to terms with the meaning of more complex mathematical relationships as well. There is one final representation, which may come at any time during the model development stage, which is a diagrammatic representation. Diagrammatic representations often require students to think outside of traditional constructs to come up with abstract visualizations of how the variables depend on each other. The construction of these representations emphasizes the interplay of the mental and conceptual models described earlier as well as how the conceptual model can be expressed concisely in the physical world. Each representation itself also stresses epistemological aspects of scientific modeling that each deserves much more detail than I will go into here, but that will be expanded on in my discussion of epistemological resources.

With their array of data representations students are then asked to present their model of the physical phenomenon that they investigated. Presenting their results to the classroom group again stresses the social aspect of conceptual models. In this instance however, students are also challenged to go beyond describing what they found and what their representations are, but to explain how the data representations can be coordinated into a complete understanding as a model. For instance, how does a specific aspect of one representation get represented in another representation, or how is a particular aspect of the physical phenomenon represented in each representation? This discussion further models authentic scientific inquiry, and often results in modifications to the models that groups present; modifying models emphasizes an aspect of modeling epistemology that I will expand on in much greater detail when I discuss epistemological resources, that scientific models are subject to change and are constrained in their scope of applicability.

The final phase of model development follows naturally from the presentation of individual group models, and that is the generalization of findings. The models that students create are based on a specific data set, from a particular apparatus, that is modeling a much more general physical phenomenon. Students are led to question limiting cases of their apparatus, as well as analogous situations that seem like they might be governed by the same conceptual model. Explicitly addressing the constraints of a model and its applicability to other physical systems allows students to confront the notion that a few key conceptual models can describe myriad different physical phenomena. This sets up the second stage of the Modeling Cycle, Model Deployment.

The Model Deployment stage requires students to reason with their mental model as elicited by physical situations that are examples of the target conceptual model, which serves to strengthen and refine their mental model as it evolves closer to the target conceptual model. Model Deployment activities can look exactly like "traditional" homework problems, or group work; however, ideally Modeling Instruction prepares students for more complex problems. For example, at Florida International University Model Deployment problems require a complete and coherent model of a physical situation as a complete response (Brewe E. , 2008). This style of response means that when students have "completed" a problem they have a coordinated set of representations that describe the system under an explicit set of assumptions, often linking several instantiations of general models together. For example, the motion of a car getting up to speed, driving for a specific amount of time, and coming to a stop within a certain distance would require linking the boundary conditions of three instantiated models: constant acceleration for the speeding up, constant velocity for the cruising, and constant acceleration (with explicit statement of the assumption that the car breaks with constant acceleration) for stopping. With all three of these models chained together students are able to then "read off" the answer to any of the "traditional" homework problems such as "what is the work done by the car from $t=2sec$ to $t=38sec$?" The benefit of such "complete model" problems is that students are shown that modeling supersedes solving traditional problems by requiring a complete solution (in that their model is able to answer any traditional problems asked of their physical scenario), and that problems that at first impression seem hard, can be worked out by making explicit assumptions and applying models in a piecewise fashion. It should be noted, that although Modeling Instruction is currently focused on introductory physics, many of the advanced problem solving techniques taught in upper division physics are fundamentally instantiations of models in a piecewise manner, focused on matching boundary conditions. At MIT this point is made explicit with their work in using Modeling Theory to train students in advanced problem solving by delivering the structure of physics in terms of models at the beginning of the course and focusing entirely on problem solving thereafter (Pawl, Barrantes, & Pritchard, 2009). Although Model Deployment activities are clearly an essential aspect of MI, they are outside the scope of this work.

Adapting Model Development Activities

The pedagogical and curricular adaptation of Modeling Instruction, Modeling Informed Instruction, has constraints based on both the structure and content of the course. Due to these constraints, Model Development activities are relegated to two-hour lab activity blocks that meet Monday through Thursday, while Model Deployment activities span the Monday, Wednesday, and Friday lecture sections as well as some of the lab activity blocks, homework, and group work. In order to keep Model Development ahead of Model Deployment, Model Development activities are engaged with a week ahead of Model Deployment. This also means that the previous model is still being deployed while the next model is being developed. These decisions were made in an attempt to maintain fidelity to the Modeling Cycle. In the rest of this chapter I will focus almost exclusively on the design of the Modeling Informed Instruction - Model Development activities, specifically how their design took into consideration the epistemological structure of modeling theories throughout their development, and how the resources theoretical perspective is folded into the analysis of student engagement with these activities. The adaptation process spanned four years and saw iterative changes to several aspects of the activities. In the remainder of this section I will discuss how each iteration focused on a particular aspect of modeling epistemology, and how changes were made for the subsequent version of the activity.

MII v1

The first iteration of MII activities began as a simple transplantation of Modeling Instruction into the two-hour lab blocks of the course. This transplantation focused on two specific pedagogical aspects of Modeling Instruction that I have yet to mention, but that are synonymous with MI: Socratic dialogue, and whiteboards. The use of Socratic dialogue in Modeling Instruction is intended to increase the social aspect of constructing models, and to transfer much of the responsibility and ownership of the modeling process to the students themselves. Whiteboards are used as communal physical spaces on which small groups co-construct their models of the physical phenomenon under investigation during the model development activity, and which are used at the end of the activity to present individual group findings and the models constructed from them. Both of these techniques are clearly emphasizing the inherent social nature of the conceptual models, while maintaining the notion that mental models reside within and are the responsibility of the individual. In the first version of MII activities both of these techniques were attempted, but with very limited success. Students came away from the activities without the sense that constructing a model was core to the activity and instead were focused on constructing the representations themselves at the surface level. As a result of the issues that came from Socratic dialogue and whiteboards I made the decision to focus on the epistemological underpinnings of these pedagogical techniques while limiting their role in the activity itself.

MII v2

For the second version of the MII activities, much of the Socratic dialogue designed to guide students through the Model Development process was unpacked and written into an activity guide, which also supported the self-pacing of groups. Several aspects of the experiment design were put into the activity guides as well. This was an attempt to focus more time on the construction of representations, presentation of models, and generalization of models. An added benefit to unpacking much of the interrogative Socratic dialogue was the freeing up of Teaching Assistants to spend more time focusing on group functionality. Group functionality focused on keeping groups on task and making sure that key discussions were being actively engaged in, which had been noted as an issue by the instructors of the previous version. The changes to the activity guide gave much of the desired effect, as students spent more time discussing how the representations related and understanding the result of their activity as a conceptual model; however, the fundamental structure of the modeling cycle and the importance of each phase continued to be an issue.

MII v3

The third version of the MII activities was the most explicit in its attention to the structure of the Modeling Cycle. The phases of Model Development were supported in an appendix of "Common Modeling Tasks" (CMT) and each activity itself made direct reference to these tasks as they came up in the course of the activity. On top of the CMT students were also asked to summarize their complete model on a single page, as a take-away replacement for whiteboards. These changes helped focus students on both the process of Model Development and the resulting complete model, the coordinated representations and their relationship to the physical phenomenon. From this version of the MII activities there were mostly minor concerns about the separation of the CMT from the individual activities, and formatting differences between certain unique models. However, this version of MII also identified a solution to an issue regarding linearization of data and student understanding of the algebraic functions used to model some of the data.

It had been found in the previous two years of instruction that students were struggling greatly with the functional dependence of variables throughout the course as a whole. In the spring semester, a few of the MII activities were given new sections that extended the qualitative description of the phenomenon to include looking at exploratory data runs. During these sections students are led through a comprehensive approach of understanding the meaning of the algebraic functional form that describes the data they see. First, students are asked to look solely at the graph as a mathematical function, and to identify the ways in which the graph itself changes as they change parameters of the algebraic function. For example, when working with the position and velocity of a pendulum as measured by an Ultrasonic Motion Detector, students see sinusoidal data. They are then asked to work with the general mathematical form: $A \cdot Sin(B \cdot x+C)+D$, with the initial parameters $A=1$, $B=1$, $C=0$, and $D=0$. When they plot this function on top of their data they see an image like Figure 2-2. This picture makes it clear that a sine function is a mathematical form that knows nothing about the physical context of their pendulum data. They are prompted to increase and decrease each parameter, A through D, and to describe how it changes the graph visually. When they have seen how the sine graph changes with a particular parameter increasing or decreasing, they are then asked to make the analogy between those graphical changes and changes to their physical phenomenon. For example, when B increases the number of oscillations in the same amount of time increases, which they identify as "*B* is related to frequency." By breaking this sequence down into two steps, students were able to identify the physical meaning of algebraic parameters and to use this understanding to inform their perception of what "good" data is. This effectively addressed an epistemological perspective that students were bringing into the classroom, where algebraic functions only needed to be understood as mechanistic formulas and not as conceptual statements about how the relationship between variables behaved.

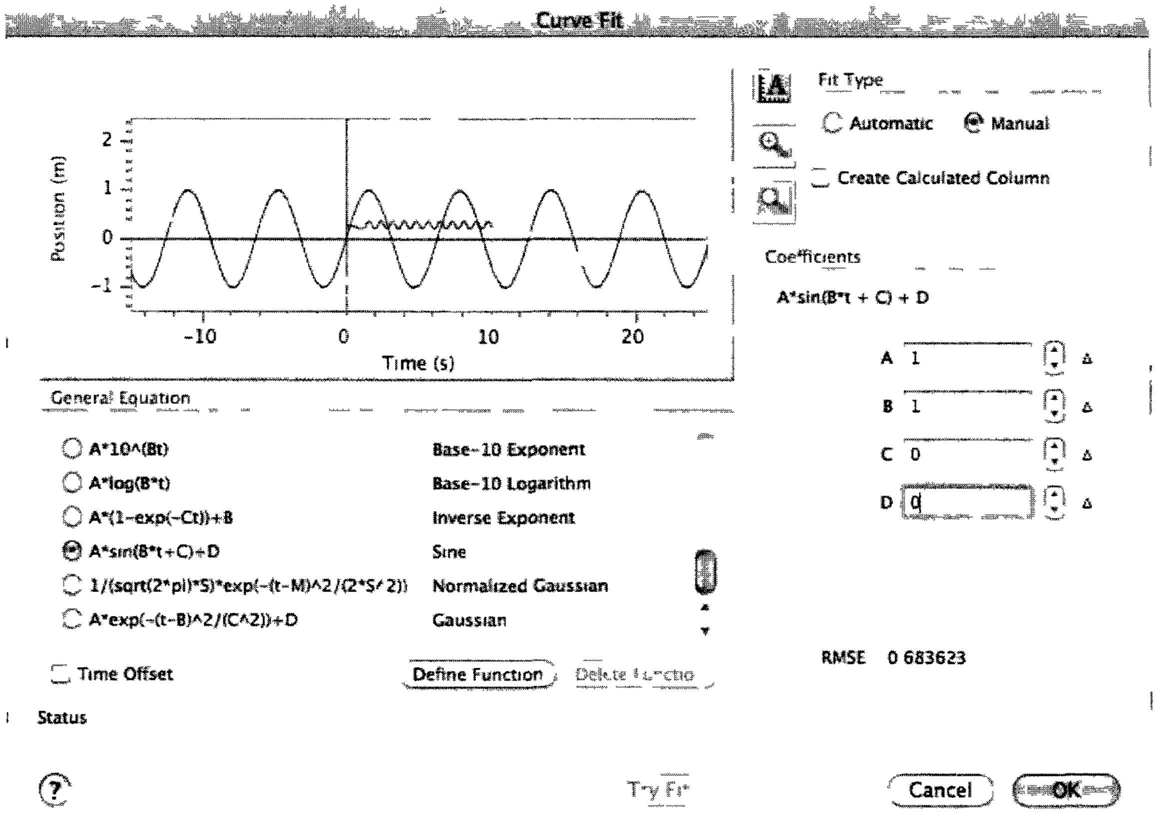

Figure 2-2 Screenshot of curve fit window with oscillation data (blue) and default sine curve (black) on top

MII v4, The Final Version

For the final version of the MII activities, each activity was reformatted to follow the same structure, and to include a section where students are explicitly asked to address the mathematical meaning of the parameters in their algebraic functions on the way to identifying their potential physical meaning. In addition to this adjustment, the artifacts that students generate in the Model Development activity were separated into two documents, lab notes and the model summary page. The separation of these two documents further emphasized the parallel emphasis on both the process of modeling and the resulting model.

Breaking Down a Single MII Activity

In this section I will walk through a complete MII v4 activity, and identify the epistemological underpinnings of each section as seen in Table 2-1.

MII Section	Epistemological Intent
Prior Concepts and Models	Connectedness of scientific models
Preliminary Model	Personal role in construction of knowledge Scoped nature of scientific knowledge
Relationships and Planning Your Experiment	Precision and reproducibility of scientific knowledge
Execution and Data Collection	Data as justification of scientific knowledge
Constructing Representations of Data	Constructed nature of scientific knowledge Scientific models as a complex and coordinated
Presentation of Models and Peer Evaluation	Consistency of scientific knowledge Role of community in validating scientific knowledge

Table 2-1: Epistemological intent of MII Model Development Activity stages.

Prior Concepts and Models

In this section of a MII v4 activity students are introduced to the basic experimental setup and any special equipment they will use. The goal of this section is to warm students up to their setting, and to get them making observations about the physical context that they are working within. Usually, this involves questions that connect the current activity to previous MII activities, and there is always a prompt for students to draw a diagram of the apparatus along with the coordinate system(s) for any measuring devices they are using.

The earlier in the activity that students make observations and have to represent them, either in descriptions or diagrams, the better for setting the context of a constructive learning environment. Tying in the fundamental idea of coordinate systems is intended to prime the interconnectedness of scientific knowledge, that the model they build in every activity is built upon earlier understanding.

Preliminary Model

The Preliminary Model section of a MII Model Development activity encompasses the Qualitative Exploration and Identification of Variables phases of the traditional Modeling Cycle and breaks these down into four parts: Introduction, Initial Observations, Connect to and Differentiate from Prior Models, and Identification of Variables. The Introduction gives a brief overview of how the entire modeling activity will proceed. In the Initial Observations part, students produce the phenomenon of study for themselves, take preliminary observations and data, and give their own accounts of what is happening. The Connect to and Differentiate from Prior Models part explicitly addresses how the phenomenon they just observed might relate to and expand on earlier models they have created. Finally, students are asked to go through Identification of Variables, where they pick out from their initial observations what they think they should take measurements of, and define these variables in terms of their current understanding and physical apparatus.

This section builds off of the first, continuing to push students to take ownership of their experiment and the understanding that they take away from it. In this section all of the prompts are geared towards students making their own observations, discussing them, and coming up with their own tentative understanding of the phenomenon that their apparatus gives them access to. There should be no "right" or "wrong" answers yet, which implicitly reinforces the idea that scientific knowledge is continually improved upon as more information comes to light.

There is a roaming part to the activity, called Mathematical Form, which I described earlier. If the data being gathered is of the time-series format, then there is usually a functional form that defines this time dependence. It is in this part that students unpack the parameters of the general function, and get a sense of how it is mapped to a physical situation. This part of the activity is sometimes repeated when the resulting data from the controlled experiment is analyzed and introduces a new functional form.

Working with a concrete experiment that produces data that follows a functional form and a data analysis program that allows manipulation of an instance of that form, gives students a unique place to connect abstract mathematical ideas to their concrete natural occurrences. This process gently lifts the veils separating the natural world (where the phenomenon and data representations are), the conceptual world (where the functional form as an abstract idea lives), and the mental world (where students are fighting to make their own sense of how all the pieces fit together).

Relationships and Planning Your Experiment

This section brings the physical reality of the experimental apparatus to the forefront, explicitly asking students to identify the full and safe range of data they can take. Then, they are asked to pick a single variable that they can isolate and control, and to devise procedure for collecting data on the remaining variables in response to the independent. All of their efforts are recorded in their lab notes, making the process of modeling something they have a concrete record of.

The intent of this section is to refine the free-exploration with which the students have thus far engaged, and to bring to bear some of the disciplinary rigor for which physics is known. The written record also serves as a way to ground students in their ideas at this stage. This allows them see where they started, and gives them something concrete to take hold of to when they need to explain their thinking. The refinement of curiosity into scientific experimentation is crucial for differentiating scientific knowledge from other explanatory knowledge, anchoring the ideas to come in an intentional and replicable investigation.

Execution and Data Collection

The collection of data is undoubtedly crucial, as I mentioned earlier. However, the activity of taking data itself is often breezed over, and considered basic. In this section students are not just asked to take their data carefully, but to pay attention to the issues that they ran into while performing their experiment, the discussions that ensued, and the decisions that they made in order to move forward.

As I said, taking data is "easy," but paying attention while taking data is enlightening. This is the part of a lab activity when students react to what they see, where the "wow" moments that we reflectively attribute to the analysis of data really take place. This is also the turning point of the activity, where everything that follows is founded. It is the implicit goal of this section to get students thinking about data as the justification for each aspect of their complete scientific model.

<u>Constructing Representations of Data</u>

Like the implicit goal of the previous section, the explicit goal of this section is to drive home the ways through which data gives rise to scientific understanding. In this section, students go through the creation of multiple representations of their data: numerical data tables, graphical plots with best fit curves, algebraic representations of the best fit curves, verbal representations of the relationship described by the algebraic equation, and sometimes a diagrammatic representation of the fundamental behavior being exhibited. Each of these representations can be seen as built from the previous, which means that they all must share in their ability to describe the phenomenon. By this I mean that each representation has a way of embodying the essential patterns revealed by the data.

This section is where students make their final moves away from taking in information from the system, and completely shift into constructing understanding through the coordinated development of the representations. The construction of representations and recording of them onto the model summary page feels like an end in itself; and students are pressed to see the representations as essential elements for understanding the model of the physical phenomenon as a whole, and not just a single equation or eloquent statement of its behavior. Separating the construction of representations and the synthesis of the model itself is intended to stress the complex structure of scientific understanding and the requirement for a model to attain cogency.

Presentation of Models and Peer Evaluation

The final section of a MII v4 activity has two parts, model preparation and discussion. The model preparation makes coordinating representations an explicit discussion topic, and identifies key issues depending on the target model. The discussion moves beyond the initial results of individual group models, and brings together all the relationships investigated by the class. This means that the models that have been constructed up to this point are only one-dimensional, in that they look at a single variable dependence; however, most of our physical models are multivariate. At this point in the activity responsibility has finally shifted away from the individual group to the community, and this emulates the way authentic science is challenged and furthered by expression within the entire community.

The goal of this section is to bring all of the independent results together, to discover, discuss, and resolve differences among the aggregated results, and to come away with a more complete and overarching model. At this point the classroom is moving beyond data as justification, and towards peer-review as a belief condition. Scientific model complexity is exposed further, as understanding becomes communal.

CHAPTER 3

A CASE FOR PRAGMATIC EPISTEMOLOGY

In this chapter I will expound the theoretical structure of epistemology that is assumed for this work by first summarizing the definition of personal scientific epistemology I developed earlier. I will then expand on this definition by addressing key discussions and research results within the PER and epistemological research communities. Next, I will push them forward with the definition and development of pragmatic epistemological resources as defined through this work. Along the way I will attempt to clarify that this chapter describes my theoretical perspective, and not the explicit conclusions that have come from my data; I save these data-based results for the final chapter of this work.

Review of Epistemology

As I mentioned in Chapter 1, epistemology is the study of knowledge and knowing. Epistemology is studied by researchers from several different disciplines, and each of them different goals and constraints for their research. For this study the broad spectrum of epistemology at large is left behind for an acute inquiry into the workings of student epistemology during the learning of physics through a Modeling Informed Instruction Model Development Activity. This acute focus requires me to make my theoretical perspective clear, and I do so by clarifying the subset of epistemology within which I situate my work as personal scientific epistemology.

Scientific Epistemology

Scientific epistemology is the study of scientific knowledge, knowledge that meets the current standards of the scientific community. Science as a whole can be treated as a model for the natural world within which we live, as discussed in Chapter 2, but it is crucial that we recognize the rules for working within this model to claim knowledge. In Chapter 1, I outlined three conditions of knowledge: truth, justification, and belief; I will now review how declaring a scope of scientific epistemology defines what I consider "expert" views on these conditions. These are not the views that we expect incoming students to have, but rather the target views that students coming out of a modeling class might have come to appreciate (Elby & Hammer, 2001).

The condition of truth for science has developed in parallel with science itself and its revolutions, and I again make the claim that for the purposes of modern scientific epistemology the truth condition has transformed into a falsifiability condition (Kuhn, 1962). I contend further that under the auspices of modeling theories, falsifiability is further weakened to falsifiable within the scope of the model being tested. I make this claim to suggest that we could call Newton's laws falsified, since we know that they are insufficient to describe physics at the quantum level; however, this is more appropriately handled within the scientific community as a statement of the limited scope of Newton's Laws as a model of the natural world. We do not disregard Newton's Laws as "not knowledge," but instead are careful in where and when we utilize them to model a physical phenomenon. The second and third conditions are a little more straightforward.

All sciences hold empirical evidence as paramount in justification of knowledge, whether that knowledge be as narrow as the spring constant for a specific piece of elastic string, or as general as the Standard Model of Physics. Each scientific discipline, and their sub-disciplines, has it's own unique guidelines for how the standards of evidence are handled, but the explicit requirement of evidence is a common thread. Without empirical evidence there is no direct connection to the natural world. Since scientific knowledge as defined herein models the natural world, empirical evidence is required. Where social sciences and physical sciences diverge is often in the realm of reproducibility, which I mentioned earlier as a credential for believability. This study itself attempts to bridge this gap, as I will make strides in Chapter 4 to encourage reproducibility within certain types of qualitative research.

Broadly speaking though, believability is controlled within science by the peer-review process. Peer review is the dialectical mechanism through which the scientific community polices itself. Referring to modeling theories as presented in Chapter 2, scientific knowledge resides in the conceptual world. As a resident of the conceptual world, scientific knowledge is governed by a group of individuals and not individuals themselves. The group therefore maintains ownership and is responsible for the caretaking of the models that are considered valuable and or valid scientific knowledge. As scientific models are found to be insufficient, their scopes may be limited further within the community, or the models themselves may be removed from the active conceptual world and relegated to artifacts (books or papers) that survive only in the natural world. Often these antiquated models find themselves in the classroom being used to illuminate scientific progress; however, as more work is done to identify the importance of explicitly developing scientific epistemology in the classroom, we may find that they can serve multiple purposes. Believability then is not a clear-cut an issue for scientific knowledge, but by embracing a modeling theoretical view of science we can at the least come to understand how it plays out within the community. In the next section I will discuss how focusing on personal epistemology affects the role of this target "expert" scientific epistemology.

Making it Personal

There are several ways of approaching epistemology, whether scientific epistemology or not, and the choice to focus on personal scientific epistemology is not without complicating effects.

Personal epistemology is the study of an individual's views of knowledge and knowing, which means that the "expert" scientific epistemology that I expounded above is the ideal target for individuals to achieve; however, their current personal scientific epistemology is not necessarily congruent with any of the expert views. In order to effectively study personal epistemology we must open our senses to the variety of views that students may express, either in their statements or their actions. This means that our theoretical perspective on personal scientific epistemology must be open to unforeseen characteristics, and not closed off from what might be considered "unproductive" scientific epistemological ideas. To better understand how I go about this, in the next section I lay out the theoretical form of personal epistemology with which I engage, in relief to other forms used throughout the epistemological literature.

Theoretical Perspectives on Personal Epistemology

In this section I use the differing theoretical perspectives on personal epistemology to motivate my choices for working within the resources framework. There are three predominant frameworks of personal epistemological theories: beliefs, stages, and resources (or knowledge-in-pieces) (Louca, Elby, Hammer, & Kagey, 2004). There are also structures within the PER literature (e.g. *e-games, e-forms, e-frames)*, which I will characterize as situated within the epistemological resources framework in a later section. Beyond the structure of personal epistemologies, there is the evident discrepancy between what we say our ideas about knowledge and knowing are and the ways in which we engage in creating, evaluating, and applying knowledge. This discrepancy I will address as an issue of "formality," and I will use four examples from the literature of researchers describing this essential gulf. Finally, as I mentioned briefly in Chapter 1, there is ongoing discussion about the limits of what "epistemology" should be concerned with. I address this issue as the "scope" of epistemology, and use it to clarify my motivation to define "pragmatic" epistemological resources.

Beliefs and Stages in Personal Epistemology

Personal epistemological theories come in three major flavors: beliefs-based, stages-based, and resources-based. Here I describe the first two, highlighting their inherent implications for instructional practice, methodological choices, and how resources-based theories may account for the same evidence. A table summarizing all three is found at the end of this section.

The personal epistemology research literature as well as PER survey style epistemological studies are dominated by models of individuals whose epistemologies are characterized as coherent mental structures that are stable and robust, they can be identified in a consistent manner within a given context (Hofer & Pintrich, 2002), (Adams, Perkins, Podolefsky, Dubson, Finkelstein, & Wieman, 2006), (Redish, Sal, & Steinberg, 1998), (Louca, Elby, Hammer, & Kagey, 2004). These belief structures are sometimes broken down along what I will call *epistemological aspects* such as the structure of knowledge, the certainty of knowledge, and the source of knowledge (Hofer & Pintrich, 2002). Beliefs about the structure of knowledge have been used to differentiate between an interconnected versus isolated nature of scientific knowledge while beliefs about the certainty of knowledge differentiate whether or not scientific knowledge is static, or always true. Examples of how these aspects might be structured are shown in **Error! Reference source not found.**1. Belief-based descriptions of an individual can account for variability within a single context by separation into such aspects, and this improves the beliefs-based framework's utility in understanding the context sensitivity and complexity of personal epistemology. In the beliefs form, the instructional implication is that personal epistemologies can be addressed through a cognitive conflict or conceptual change-like system of elicit, confront, replace (Hofer & Pintrich, 2002). These instructional techniques are correlated to the idea that beliefs are deep-seated in individuals and resistant to change unless addressed directly; whereas, the priming and activation of resources is seen as more easily manipulated. Methodologically speaking, beliefs-based forms of personal epistemology are accessible through clinical interviews that provide declarative evidence as well as survey instruments with explicit interpretational schemes; I will discuss this issue in detail in Chapter 4. Resources-based theories account for the same persistent structures by allowing for coordinated networks of resources to exist as stable structures; this stability has been described in detail as the *plasticity* of resources (Sayre, 2007). These structures can include resources that describe certain epistemological aspects, such as *knowledge structure, knowledge certainty, and knowledge source*, among others. Coordinated activation structures of resources improve on the beliefs-based accounts by allowing for more complex context dependence of participant responses as seen in several studies (Louca, Elby, Hammer, & Kagey, 2004). I will expand on the complexity of this context dependence in the next section on "formality" of personal epistemologies.

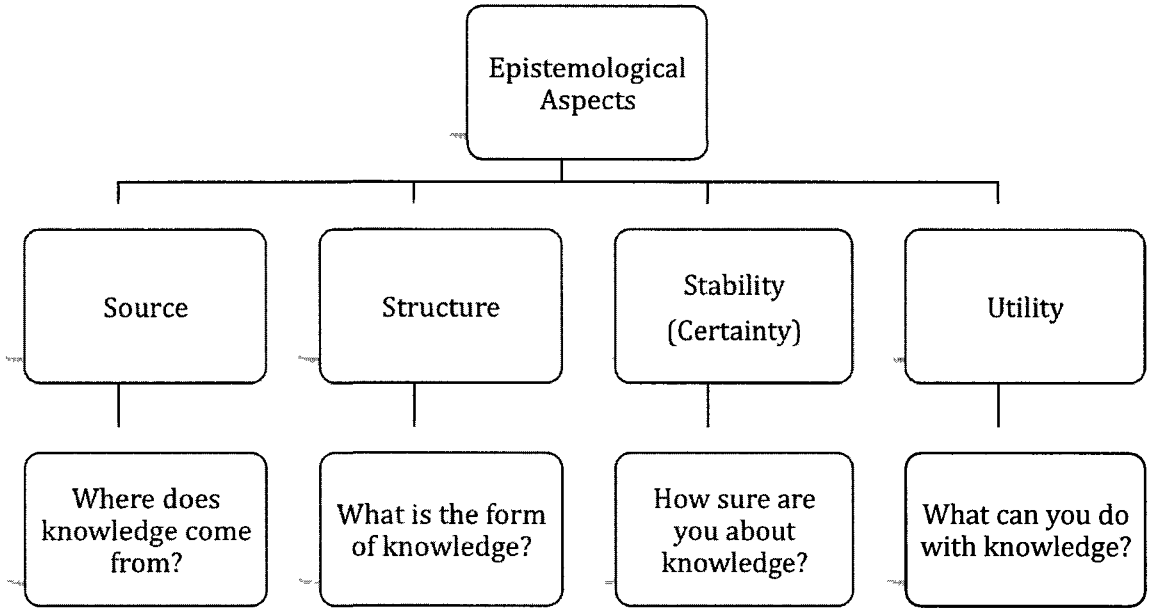

Figure 3-1: Epistemological aspects and the questions they target.

The personal epistemologies described by stage models are built upon evidence for developmental progressions that occur over years and whose transitions are frequently triggered by significant life events or accumulated experience (Belenky, Clinchy, Goldberger, & Tarule, 1997; Perry, 1970; King & Kitchener, 2002). Such models are constructed through longitudinal interview methodologies (Belenky, Clinchy, Goldberger, & Tarule, 1997; Perry, 1970) or well-structured clinical interviews (King & Kitchener, 2002). For example, Belenky et al. describe the progression of women's ways of knowing as discovered through interviewing a small group of individuals throughout several years. Due to this methodology the stages they develop to describe women's epistemology are significantly affected by the individuals they chose to interview, as well as their own analytical perspective. On the other hand, their methodology cast light on possible triggers to changes in epistemological

Category	E-Stages	E-Beliefs	E-Resources
Granularity of Personal Epistemology	Complete Epistemology	Set of E-Beliefs; Along E-Aspects	Coordinated E-resources; Span E-Aspects
Scope: Knowledge and Learning	Knowledge & Learning?	Knowledge & Learning?	Knowledge & Learning?
Scope: "What I Say" vs "What I Do"	Do & Say	Say	Primarily Do; (can model "Say")
Contextual Dependence	Weak	Moderate	Strong
Methodological Implications	No Explicit Implications	Surveys & Clinical Interviews	Observation of Practice & ABRI
Instructional Consequences	Developmental Limitations	E-Conceptual Change	Analogical Bridging
Stability	Highly Stable; Significant effort to change	Stable in context; Some effort to change	Variable; Easily perturbed in a context
Example	WWK, Perry, RJM	Hofer & Pintrich	Hammer

Table 3-1: Stage, Belief, and Resource Frameworks differentiated along 7 categories, and references to their use in research.

complexity. For example, child rearing was found to be a significant factor to some women's transitions from received knowing perspectives, where all of their knowledge came from figures of authority in their lives, to constructive and self-owned perspectives on knowledge, where they were confident making knowledge claims based on personal experience. Alternately, the Reflective Judgment Model uses a different sampling method, whereby many individuals of a variety of ages and experience are asked about unsettled issues that do not have right and wrong answers, and are asked to discuss their thoughts in individual interviews. For example, ill-formed questions cover discussion of the theory of evolution, and the degree of insecticide use on cropland, as well as other issues on which "reasonable people reasonably disagree" (King & Kitchener, 2002). Responses are then evaluated along a spectrum of seven stages from the least complex views of knowledge, "pre-reflective," to most complex perspectives on knowledge claims, "reflective." Along the epistemological aspect of knowledge certainty, or "justification of beliefs" as discussed by the authors, pre-reflective epistemologies take knowledge as authority driven, while the reflective epistemologies follow evidence driven reasoning with explicit acknowledgement of uncertainty in their reasoning and conclusions. These stages were correlated with stages of educational experience, with the most complex measured epistemologies coming from only a fraction of post-graduate students, and even these individuals were not reaching the highest stage of the model. In terms of instruction, such theories provide a structure that describes where students are functioning in their development, and perhaps what their next development will be. This allows instruction to be tailored to student levels of epistemological complexity. However, a stage-model by itself lacks the power to appropriately handle the context dependence of participant responses, and provides no description of the mechanisms for moving through stages. For example, the Reflective Judgment Model relies on unsettled controversies that they call "ill-formed" to identify epistemology; however, changing the context of the questions to more familiar or "well-formed" issues where society has a consensus may indicate different levels of reflection for the same individuals. In terms of resources-based theories, stages can be reconstructed by identifying the essential elements that underlie their definition among specified epistemological aspects. This reconstruction can even be done using the same indicators in the data, but refraining from associating them with concrete stages along a continuum. Stable resource structures have been identified in various contexts as a way of handling compiled knowledge, yet these structures need not be anchored to a strict developmental progression (Wittmann, 2006; Sayre, 2007).

Resources-based Theory of Personal Epistemology

The resources perspective, as I have shown, is able to account for the constructs of both beliefs-based and stage model theories of personal epistemology. But these comparisons do not encompass the entirety of resources-based theories, which I describe below.

Resources as a theoretical construct were originally adapted by David Hammer in the image of Minsky's 1986 computational model of the mind as a multi-agent society (Hammer & Elby, 2002; Hammer & Elby, 2003; Louca, Elby, Hammer, & Kagey, 2004). In this metaphor, it is the coordination of independent entities that gives rise to emergent phenomena, which describe the complex behavior of the overall system. Resources at the fundamental level are small bits of knowledge that can be used over and over in a variety of contexts. These bits of knowledge can take many forms: reasoning, epistemological, mathematical, etc. Individually, resources are neither right nor wrong, but can be applied productively or unproductively depending on the context in which they are activated. For example, when dealing with gravitational attraction, the resource *closer means stronger* applies productively; however, in the context of the nuclear strong force this resource would be unproductive, as the strong force obeys the opposite relationship between distance and strength. As simple elements resources are inherently weak in explanatory power; however, when activated in concert with others, resources can be complex and powerful descriptors (Wittmann, 2006; Sayre, 2007). It is important to note that resources are research-based constructs that are essential elements of a modeling theory of learning, not necessarily mapping to neurological patterns in the brain or identifiable by those activating them in situ.

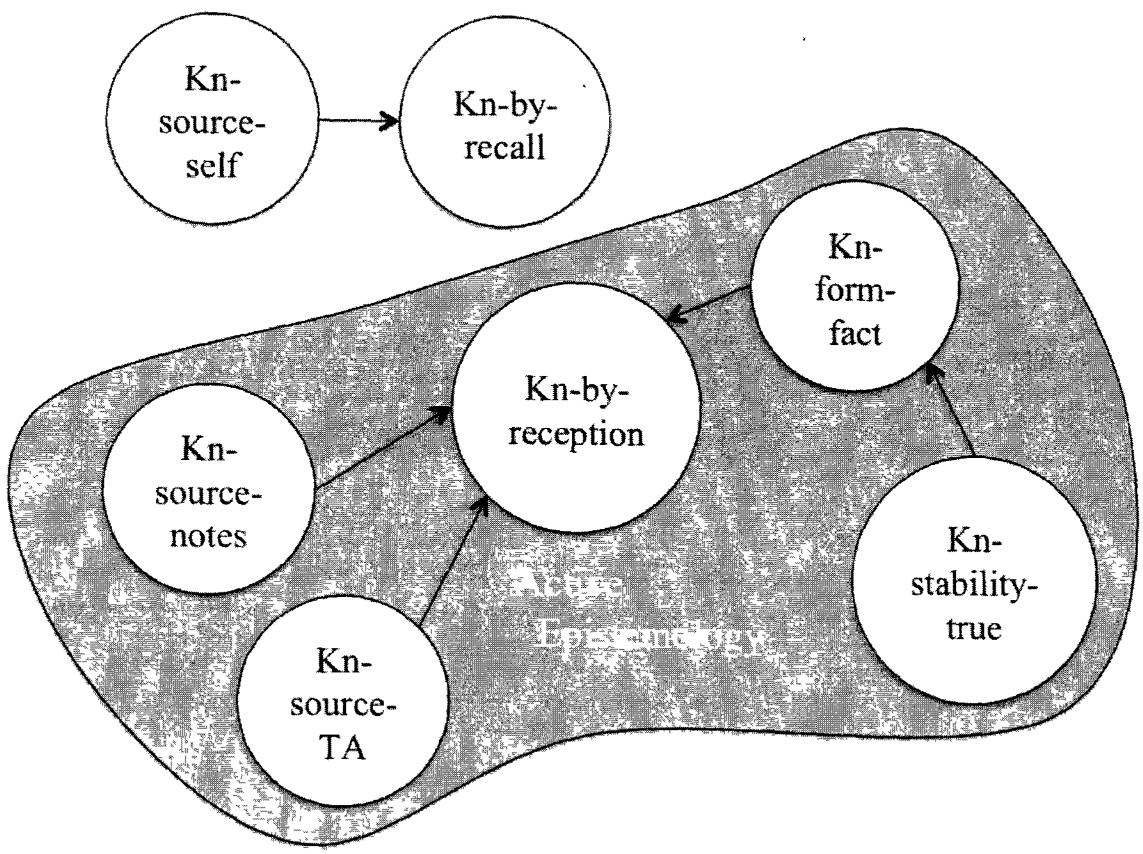

Figure 3-2: Personal epistemology as coordinated activation of epistemological resources.

Resources activated by individuals in a given context are identified through various means depending on the type of resource being investigated as will be described in full in Chapter 4; however, the fundamental dynamics of resource-based theories are similar. As I stated, the original concept of a resource is tied to an ecological or society based model of the mind with independent agents working in concert to achieve complex emergent behavior. Resource theory appropriately borrows many of the fundamental ideas of emergence and network dynamics from complexity theory and multi-scale systems. Resources in general are scale free elements, with primitives free to be activated in a network that involves compiled resources that themselves have internal structure. For example, the act of matching boundary conditions may involve a compiled mathematical resource such as *logarithmic derivative,* which is activated in a network with the reasoning primitive *balancing*. Scale free dynamics such as this will be touched on again in discussing the interactions of epistemological resources and epistemic frames in the next section. Resources can be envisioned in resource graphs, which also help define possible dynamics within a resource activation network (Wittmann, 2006). However, for my research the detail of these dynamics is not relevant. The treatment of data forthcoming in Chapter 5 is held to the more fundamental levels of epistemological primitives, and I leave the dynamics and interactions of these to later investigations. Even with this limited application of Resource Theory, there are implications for instruction.

Resources inform instructional design by revealing a positive approach to dealing with incorrect reasoning (Scherr R. E., 2007; Louca, Elby, Hammer, & Kagey, 2004). Rather than viewing student difficulties as misconceptions that require wholesale change, resources allow instructors and curriculum designers to view student difficulties as either missing or inactive resources. Instead of requiring a complete overhaul of the way a student thinks in a given context, the instructional goal in resource theory is to help students either attain new resources, or improve the activation and coordination of resources that they already have but are misapplying. This model underlies how many instructors implicitly use analogy, as well as the research-based notion of "anchoring conceptions" (Clement, 1982).

The methodological implications for working within a resources based theory is the topic of Chapter 4; however, at this time I will claim that there are different requirements of evidence for identifying resources depending on the type of resource you are targeting.

Distinctions Among Personal Scientific Epistemology Definitions

In colloquial settings we often hear the statement "do as I say, not as I do;" as it turns out, this adage is truly an essential aspect of effectively studying personal epistemology for education research. Several researchers have independently identified and described a gulf between three measurements of scientific epistemologies that I will describe as "scope:" what individuals think professional scientists would say scientific epistemology is; what individuals, students and teachers alike, report as their scientific epistemology; and how they actually work with scientific knowledge (diSessa, Elby, & Hammer, 2002). I will describe my understanding of four of these descriptions and then take away from them a single effective statement of "what I say" and "what I do" being incongruent in the realm of epistemology. The distinction between professional science and school science is a further distinction that is outside the scope of this research, although it helps define my work and itself is worthy of deeper understanding. I consider these separations essential for the pragmatism of epistemological research within education research, as changing what people say is of little value compared to changing what people do.

Locating eight distinctions of personal scientific epistemology requires me to be explicit about the dimensions that these distinctions operate on. There are three major dimensions: (1) perspectives on professional science versus personal experience with school science, (2) statements about scientific epistemology versus actions while doing science, and (3) ideas about knowledge and knowing versus ideas about knowledge, knowing, and learning.

Hogan in her work on students' views on the nature of science, which includes scientific epistemology, defines "distal" and "proximal" ideas about the nature of science in terms of axis (1): "distal epistemology" describes student ideas about professional scientists' epistemologies, and "proximal epistemology" describes student ideas about their own scientific experience in school. Along axes (2) and (3) both of these distinctions are located similarly: statements about scientific epistemology, and ideas about knowledge, knowing, and learning.

Redish and Louca et al. on the other hand define their categories along axis (2). Redish describes "declarative" and "functional" epistemologies in analogy with neurological knowledge and control structures, while Louca et al. describes "professed" and "enacted" epistemologies in terms of stated by individuals versus inferred from observation. "Declarative epistemology" and "professed epistemology" fall on the statements about scientific epistemology side, while "functional epistemology" and "enacted epistemology" fall on the actions while doing science side. In terms of axes (1) and (3), these researchers make no explicit distinctions; however, my understanding from their work is that all four of these definitions fall under personal experience while doing science and cover ideas about knowledge, knowing, and learning.

Sandoval rounds out the pack by making his distinctions clear along all three axes, and is the only one to explicitly lean away from ideas about learning on axis (3). He defines "formal epistemology" as (3) "the set of ideas about scientific knowledge and its production that (2) students appear to have about (1) professional science." To be clear, I interpret this as statements students make on axis (2). Conversely, he defines "practical epistemology" as (2) "the set of ideas that students have about (2/3) their own knowledge production in (1) school science." After making these explicit definitions, Sandoval goes on to elaborate on how one might access "practical epistemology," which makes it clear that his intent is to focus on their actions while doing authentic scientific inquiry activities in the classroom environment. His elaboration allows me to claim that he distinguishes his "practical epistemology" from Louca's "enacted epistemology" only in its explicit disregard for students' ideas about learning that may come from the academic context, and not scientific aspects of their inquiry activities.

From these explicit distinctions of epistemology intended to clarify what we as science education researchers should be studying, I find myself ready to make a singular definition of "pragmatic epistemology" that includes my theoretical framework, as well as my position along these axes, and Sandoval's careful attention to authentic scientific inquiry activities.

Pragmatic epistemology is the resource-based description of student approaches to authentic scientific inquiry learning activities.

I find this definition places me on the personal experience with school science end of axis 1, the actions while doing science end of axis 2, the ideas about knowledge, knowing, and learning end of axis 3, and makes explicit my focus on authentic scientific inquiry activities which for this study are my Modeling Informed Instruction Model Development Activities.

Integration with Epistemological Constructs in PER

PER already has several theoretical epistemological *structures* that continue to be productively applied within the community and are described as congruent with a resources theoretical framework of personal scientific epistemology; however, it would be naïve of me not to review this integration here. I will follow the chain up from epistemological resources, through epistemic games and forms, epistemic frames, and finally the epistemological messages that we use to drive the dynamics within and among these structures.

Epistemic Forms and Games

Epistemological resources as described are scale-free structures, in that they can encompass a large range of theoretical constructs. Two well-defined and productive epistemological constructs that have come out of PER are epistemic forms and epistemic games. Epistemic forms are structures of knowledge, such as lists, matrices, free body diagrams, vectors, and so on. These structures range from as simple as a single scalar quantity, to as complex as a complete scientific model. The goal in enumerating epistemic forms is to identify the target structure of knowledge building activities. In general, these epistemic forms are simply a particular type of epistemological resource.

Since resources can have internal structure when more fundamental independent resources are shown to exist, Resource Theory has a very elegant way of integrating epistemic forms. For example, let us consider the epistemic form of a *data table*. A *data table* is composed of two more fundamental epistemic forms, *ordered pairs*, and *lists* coordinated to create a knowledge structure that could be considered an ordered pair of lists or a list of ordered pairs. We can then discuss a *data table* as either the compiled resources of *list* and *ordered pair* or as a resource itself. However, knowing the structure of knowledge is only half of this limited battle. How do we create knowledge that satisfies these forms?

Epistemic games help answer this question; they define how the target forms are populated with information, when the games are engaged with or exited, or if the target epistemic form is the wrong way to proceed. As Collins and Ferguson define epistemic games there are a few key aspects: the target epistemic form, the allowed moves for populating the form, the possible transfers among or out of the game, and the constraints on the game as determined by the target epistemic form. Again, as resources are scale free entities, epistemic games can be modeled as dual epistemological resources and process resources. In order to argue for this, I will define how the constituent parts themselves can be identified as resources. More complete sets of heuristics for identifying resources are given elsewhere (Sayre, 2007) (diSessa A. A., Towards an Epistemology of Physics, 1993). Earlier I described how a target epistemic form is itself a resource, and I consider that sufficient for the first constituent of an epistemic game. The allowed moves within the game must also be seen in terms of resources. For example, a *list-making* game allows four basic moves: items to be *added* or *removed* from the list, and items to be *combined* or *split* apart. These moves can be considered resources that are activated in order to move forward in the game. These resources might be labeled in very plain terms as *add item, remove item,* and so forth. When activated as epistemological resources, the content of the list changes. The list itself is represented outside of epistemological resource theory; therefore, I will not go into how it may be modeled. Transfers into and out of epistemic games are similarly modeled as resources. For example, an unordered list-making game may be insufficient for the purposes of the list, and once this is identified the active epistemological resources may change from *list-making* and its subsidiaries to *ordered list-making* or *tree-making*. These two examples of new games have different, but related, target epistemic forms, and would be likely transfers that are made out of a *list-making* game. Finally, the constraints on the epistemic game must also be modeled as resources. Constraints are similar to modifiers for the moves available. For example, I may wish to *add* an item to my list, but first it must satisfy the constraints of the game: that the items be *distinct*, that the *list* have more than one item, that the list sufficiently *cover* the answer space of the question, and that the list have some coherence through the items being of a *similar* purpose. When all of these pieces are put together an epistemic game might look like a rather large resource, complete with a set of moves, target form, constraints, and transfer conditions. I should note that I have revised Collins and Ferguson's original statement of epistemic games by considering the entry conditions of an epistemic game to be a valid transfer move from another game. This description of epistemic games as resources may make it seem as though resources-based accounts can be created to underlie almost any other theoretical construct. In many ways I believe this to be true; however, at this time my goal is only to show that the modeling power of epistemic games and forms can be replicated within the resources-based theoretical perspective so that I can perform my research at the level of resources without losing the possibility of identifying games or forms within my work.

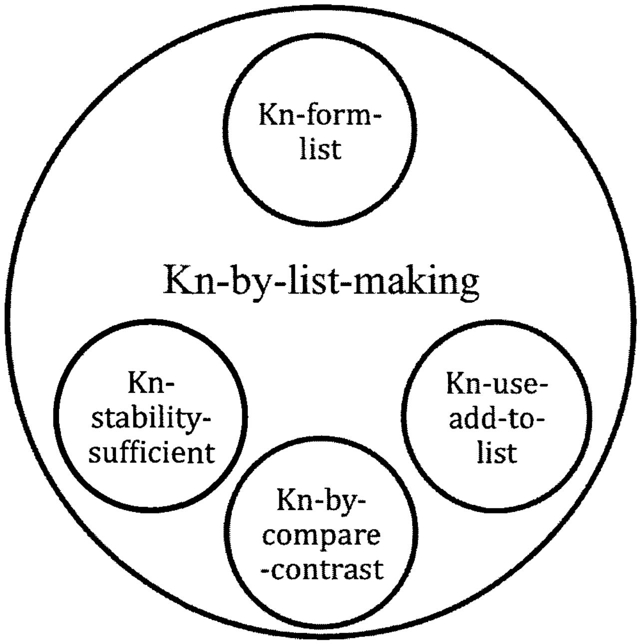

Figure 3-3: Example nested resource description of the epistemic game "list-making." Resources shown are examples of target form, constraints, transfers, and moves.

Epistemic Frames and Messages

There is yet a larger salient epistemological structure that is used within the PER community to describe the way that activities are perceived by individuals and groups. These structures, called epistemological frames, are adapted from discourse analysis as a way of describing how individuals or a group would answer the question "what is going on here?" (Redish, 2003; Tannen, 1993) Framing in this way is a tool to assess how individual and group behavior to the same activity can vary based on other contextual factors. Several productive research findings have come out of framing analysis of student work in learning physics; however, the variety of frames that are reliably identifiable are few and rather broad. For example, the *sense-making* frame is a common descriptor, and it is defined by aggregating aspects of individual behavior such as body positioning and vocal register (Scherr & Hammer, 2009; Scherr R. E., 2009). It is claimed that frames influence the availability of resources to groups and individuals, or that within a given frame certain resources become more likely to be activated (Redish, 2003). In this way frames are actually defined in terms of Resource Theory, and they might be mapped as a community of resources in the mind as society analogy. The proposed mechanism for this behavior is that a frame establishes a persistent context to the activity, until the frame is explicitly shifted out of, and that this context is established to determine a common interpretive framework within which a group can function. Viewed in this theoretical way, it is essential for productive group progress that at least some of the members of a group establish the same epistemological frame when working collaboratively.

The interactions that negotiate, shift, and establish, frames have been called epistemological messages, and can be explicit or implicit perturbations to the system of epistemological resources. For example, a group that is working diligently in the *filling out a worksheet* frame may be working in a *list-making* game, where the exhaustiveness of the list is valued over its specificity. Then, their TA comes by and asks a pointed question about what they mean by an item in their list. This question acts as an epistemological message, which might be intended to shift the group's frame into a *sense-making* frame where they can engage in a *compare-and-contrast* game. In this new game the group focuses more explicitly on comparing and contrasting the selected item with other items in their list, or to express their individual understandings of what is meant by the item in the list, such that the *distinctness* condition of the *list-making* game becomes the primary goal of the group collaboration. In this way, a simple TA interaction might lead to a complete shift in the way the group is engaging in their activity. Conversely, the group may ignore the TA question, or matter-of-factly respond with a definition and return immediately to *list-making*, in which case the TA's bid to make the group change frames with an epistemological message was a failure. In terms of epistemological resources, I would consider epistemological messages outside of the pragmatic epistemology system as an element defining a change in context. That being said, epistemological messages are still essential aspect to the resources model as a whole because they describe a possible mechanism for changing an individual's pragmatic epistemology.

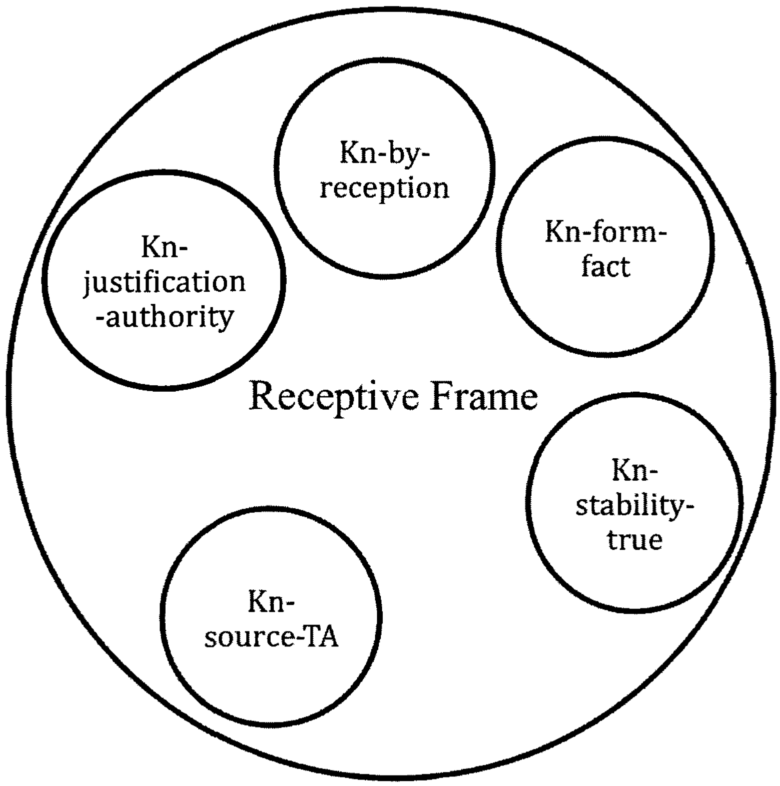

Figure 3-4: Example resource description of epistemological frame for receiving knowledge from a TA.

Specificity of Epistemological Resources

In the last few sections I have made free use of established naming conventions from the PER literature for epistemic games, forms, and epistemological frames. A main thrust of Chapters 4 and 5 however, is my claim that many of our theoretical structures within the Epistemological Resources Model are insufficiently specific. This may increase the reliability[1] of resource or frame applications due to their encompassing nature, but the validity[2] of these resources and frames becomes suspect through the

[1] Reliability as used here refers to the ability for independent researchers to apply the same identifier to data with consistency.
[2] Validity as used here refers to the notion that students identified as in a particular frame or applying a particular resource may be mimicking the identified behavior and not authentically engaged in its defining activity.

generality of their definitions. For example, *knowledge as propagated stuff* is an epistemological resource commonly referenced within the literature (Hammer & Elby, 2003); however, this seems to be a larger order resource category, or container that circumscribes several more salient and finer-grained resource that I will identify in Chapter 5. Similarly *sense-making* as a frame likely encompasses several different cognitive activities across the group members, which may or may not involve reasoning about understanding because the frame is identified through behavioral and paraverbal cues (Scherr & Hammer, 2009).

CHAPTER 4

METHODOLOGY

In this chapter I will discuss and elaborate on the methodological journey I undertook to prepare for identifying pragmatic epistemological resources with claims of validity and reliability. First, I will review the distinction between methods and methodology, and tie this to my major methodological influences and constraints. Next, I will explain the process of designing my artifact-based reflective interview methodology based on my research goals and questions. Then, I will walk through a complete data acquisition and analysis sequence, discussing in detail the choices I made and the effect of these choices on my research as a whole. Finally, I will put forward an inter-rater reliability measure for one of these interviews, and discuss the claim that my methodology uniquely provides a reliable and valid approach to epistemological resource identification.

Methodology vs Methods

In this section I describe the difference between a set of methods applied during a study, and the systematic understanding of how these methods are chosen, their impacts on the study, and the role of the researcher's focus throughout engagement with these methods (Schram, 2006).

Methods

The set of methods used in a research program is a simple statement of what was done and how it was accomplished. Under this definition, I would explain my methods throughout this study as follows: group selection for in-class video taping by IRB consent availability; video taping of group activity during a Modeling Informed Instruction Model Development Activity with a single wide-angle shot and table-top microphone; review and non-interpretive description of the in-class video in two minute sequences; selection of in-class video clips based on MII activity structure and student engagement; preparation of an interview protocol based on episode selection and epistemologically oriented questions; video taping of one-on-one interviews following the individually prepared protocol; transcription of interviews; three tiered coding of transcription focusing on location in the activity, the intent of the interview question, and the epistemological interpretation of participant responses; and finally, correlation analysis among interview codes.

Such an explanation of this research study is mostly coherent, it describes the activities that took place during the research; however, it does not have the essential depth that comes from articulating why these methods were used, how those choices change the data achieved through those methods, and the role of researcher self-awareness that is crucial for understanding the results of the study.

Methodological Influences

For the rest of this chapter I will be delving deeply into the details of my methodological choices; however, before that begins I will briefly describe the three key influences on my methodological development. First and foremost, my methodology is designed to access the data that I believe is required to reach my research goals and answer my research questions. This design has three major influences: modeling theories of science, pragmatic epistemology, and grounded theory.

The data I am using to describe students' pragmatic epistemologies comes to me through student engagement in the MII activities that I designed as described in Chapter 2. The design choices made in creating MII, especially the underlying philosophy of modeling theories of science, influence the results of this study, as they are a primary source of epistemological messages being transmitted to the students that I am studying. In fact, if this were not true, my research questions would not make any sense, as I am attempting to evaluate the effectiveness of this activity design. In the terminology of qualitative inquiry, the *locus*[3] of my study must be put in terms of the deep integration of the study within the overarching course reform project, the MII activities, and my interview process (Schram, 2006). Identifying the locus of my qualitative inquiry in this way is an essential aspect of developing the credibility of my results, because the data upon which I base my results is a product of this complex and overwhelming network of influences. In Chapter 5 I will discuss the proof of concept for correlating the pragmatic epistemological resources I apply to the interview data and the design of the MII activities; such claims are embedded within the locus as I have identified it, and should not be generalized without contemplation of how they came to be.

As I just mentioned, the end result of this research is the identification of pragmatic epistemological resources based on privileged knowledge of student personal epistemology. With the explicit locus identified, I can move on to discuss the *focus*[4] of this study: the engagement and approach that students take to the MII activities as

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[3] The locus of a qualitative inquiry is the relevant context within which the study takes place.
[4] The focus of a qualitative inquiry is the phenomenological target of the inquiry.

modeled through the theoretical lens of pragmatic epistemology. The theoretical lens of pragmatic epistemology is the second major influence to the methodology of this study; it defines the way in which I attended to the data as it was coded. As the coding of the data is the substrate upon which the analysis of student epistemology occurred, the effect of this theoretical lens is central to the claims that I make in Chapter 5.

Finally, my overall approach to developing and identifying pragmatic epistemological resources from the reflective interviews that I completed is most directly influenced by grounded theory (Schram, 2006; Charmaz, 2006). There are several essential aspects of the grounded theory tradition, and I can't claim that I authentically engaged with each; however, I do claim that the tradition of grounded theory acted as a concrete reference that helped me clarify my own methodological choices. The key aspects of grounded theory that I will discuss are: a-theoretical approach to data analysis (one should not have a preconceived theory that they wish to apply to their data, a grounded theory comes out of the exploratory data analysis), parallel data gathering and analysis (one should begin analyzing data as soon as it exists and continue collecting data concurrently as the theory develops), intentional data selection (one should choose to take new data when and where it will help complete the developing theory), two-stage coding through constant comparison (one should first "open-code" their data, and then refine those codes into "focused-codes" by comparing the open-codes across the body of data). I will explain how these key aspects of grounded theory played a role in my methodological design in the next section.

Design of an Artifact-Based Reflective Interview Methodology

In this section I will discuss how my core research goals helped me identify two methodological concerns, how those concerns were addressed, and finally the consequences of the way those concerns are addressed. I reserve the detailed walk-through of the methodology as it plays out in practice, complete with discussion of smaller decisions, for the next section.

Key Concerns: Validity and Reliability

The goal of this research has always been to describe student approaches to reformed laboratory activities, and within "student approaches," to focus on personal epistemology. A fundamental issue with studying personal epistemology is that it is located within the mind of an individual. Two major concerns arise: the *validity* of the description of personal epistemology, and the *reliability* of this description. Validity is required to claim that the account given of a student's pragmatic epistemology is close to the actuality of how students' actions are shaped by epistemological ideas. Reliability is required to claim that an independent researcher can perform this type of epistemological analysis, with a reasonable claim to similar results. A key point to reiterate here is that our description of their pragmatic epistemology, as defined in Chapter 3, is not intended to reflect the actual epistemological structures in their mind that give rise to their behavior, but to identify effective structures as describable within our theoretical framework.

Addressing Validity and Reliability

Validity as defined above benefits from data triangulation as defined in qualitative inquiry as the use of multiple data sources to improve the depth of understanding that the researcher can achieve. One approach to this type of validity is "member checking," which involves bringing the analysis back to the participants for verification that the data they provided was not misinterpreted (Otero & Harlow, 2009). For this study however, I focus on gaining privileged knowledge about students' ideas and their approaches to the learning activities as they happened during the activity itself. This privileged knowledge about an individual's personal epistemology requires interaction with the individual in order to transcend behavioral observation. Studies that lead to surveys, such as the C-LASS utilize student interviews to develop categories and ensure construct validity (that questions are understood as they are intended); however, these surveys do not utilize authentic student observation. For validating interpretations of student observations, privileged knowledge is essential. Current research that focuses on epistemological frames is limited to behavioral clusters to indicate coordinated activity, and verbal, paraverbal[5], and non-verbal cues to argue for interpretation of these clusters as large grain sized epistemologically relevant structures (Scherr R. E., 2009; Scherr & Hammer, 2009). These frames are therefore, not quite what is sought after in studying personal epistemology. To address this concern, and gain access to the privileged information required I developed an artifact-based reflective interview protocol. This protocol isolates key moments from the classroom activity, brings video clips of these moments into an interview to situate the students in that moment of the activity, and asks students to elaborate on the clip of their classroom activity. This process provides a reflective narrative on moments that are identified as epistemologically important, which I argue is privileged information about students' personal epistemologies. This approach is in contrast to the teaching-learning interview protocol, that provides in-the-moment access to student cognition, but that is fundamentally a different context than the authentic

[5] Paraverbal cues include pitch change, emphasis, and pacing, among others.

science inquiry learning activities that are the target of pragmatic epistemology (Chini, Carmichael, Rebello, & Puntambekar, 2009).

Individual researchers watching classroom video may attend to distinct phenomena, which is an issue of reliability for this interview process. In order to mediate this effect, the artifact-based reflective interview protocol preparation is well-defined. For example, clip selection focuses on the structure of MII activities, in accordance with the research aims, and the core ideas of pragmatic epistemology are explicitly communicated to the independent researcher. I will explain this reliability in detail at the end of this chapter; however, the reliability of the coding of interviews for the production of pragmatic epistemological resources is not addressed in this study. This means that even though we will show that generating interviews to access the privileged information described above is a reliable process, the analysis of the interviews is dependent on the individual researcher for the time being. The codes that are applied to the interviews are defined, but there is no independent coding as of this writing.

Implementing an Artifact-Based Reflective Interview Protocol

In this section I will walk through the entire research process, from selecting video taping groups during MII activities to applying and analyzing pragmatic epistemological codes. Along the way I will discuss the concerns that arose, how these were addressed, and effects of those choices in a comprehensive manner.

Group Selection for Natural Classroom Video

This study begins and ends with the willing participation of students according to their election as overseen by the Institutional Review Board (IRB) for research regarding human subjects. The IRB requirements for this study are such that taping of groups in their usual classroom activities is an opt-out decision, whereby students have to elect not to participate; however, the interview process falls under a separate opt-in decision, which creates the only self-selection bias identified in this study. This self-selection bias is slightly mitigated in that students who do not opt-in for interviews are still able to be video taped in class, and their interaction with the other group members is able to be discussed in interviews. However, groups that do not include any students that had opted-in for interviewing are not selected for in class video observation.

Individuals are assigned to groups at random, and these groups are assigned to tables within the classroom at random; however, all videotaping occurs at the back tables in the classroom so that the video camera and microphone setup are as unobtrusive as possible within the classroom setup. There may be selection effects due to this back-table-only protocol; however, neither the TAs nor my personal experience as a TA for this course gave any indication that these groups' behavior differs significantly from any other group in the class.

The final selection protocol is to videotape on only one-day per week, choosing a single group in each lab during that day to observe. This protocol is put into place for practical reasons, as the rest of the methodology is time consuming and limiting the amount of data looked at during a single week is essential. As each lab group stays the same for several weeks and each student is assigned to a specific lab section, this protocol allows me to sample a large variety of individuals and groups without being a constant presence in the classroom. This lack of researcher presence is in stark contrast to the methodology of ethnography, where the researcher takes the role of participant-observer, and their presence in the classroom is an essential aspect of the research.

Video Taping Natural Classroom Video

The videotaping itself is initiated by my setting up the camera in the classroom before students arrive, and waiting for the entire group that I plan to videotape to arrive. Once the class period begins, hopefully with the entire group present, I record each participant and give an informed consent speech that covers the following basics: that participation does not affect their course grade, that I am looking to observe them as they normally execute their lab, that they can and are encouraged to speak their mind, that I will be looking at the way they approach the lab (not evaluating their mastery of the content), that participation is strictly voluntary (such that any individual is welcome to turn off the camera at any time to indicate that they no longer want to be involved), and that I may contact them individually about interviews regarding the video within a week.

Once I deliver my speech, I leave the room for the duration of the class period and return to start the next period in the same fashion.

Describing Natural Classroom Video

Once the Natural Classroom Videos (NCVs) are recorded I download them into Transana, the video transcription and analysis software that I use for all video work in this study, and which will be discussed periodically. I then watch each NCV in Transana, and write a non-interpretive description with timestamps at least every two minutes. For example, when students engage in discussion I record that they are discussing an issue, but do not note my impression of their certainty; similarly, I describe students as "reacting" to stimuli, not "surprised by" or "confused by" their observations. The purpose of this description is to provide a baseline account of the activity in the video, to give a common ground for the forthcoming clip selection process, and to provide easier access to particular moments of the video.

Selecting Groups for Interviews

Each NCV is described in the same fashion, leading to three to four described NCV's per week, only one of which leads to prepared interviews (except in the Spring 2009 data corpus, where three interviews were prepared based on one week of NCV). The choice of which group NCV to prepare for interview depends on two major factors: how many group members are willing to participate in interviews, and how rich the NCV is. The number of group members willing to participate in interviews is another self-selection bias; however, the ability to access multiple individual student perspectives on common clips of group activity is decidedly unique and a strength of this methodology as it may shine new light on the concept of epistemological frames (Scherr & Hammer, 2009). The "richness" of NCV depends on factors such as the amount of talking that group members do, the physical engagement of the group members in the activity, and the general energy level of the group members. These factors are important because the goal of this methodology is to access student personal epistemologies. Although quiet groups would give valid data on pragmatic epistemology, the use of video data in this methodology is such that groups that are more expressive yield more easily accessible and illustrative data for its descriptive goal. In essence, selecting clips from a quiet NCV is difficult because there is little information to cue off of.

Selecting Video Artifacts for Interviews

In order to create artifact-based reflective interviews, the artifacts for the interview need to be selected. For this study, the primary artifacts are clips of the NCV, with supporting artifacts being a printed copy of the activity guide, and the groups' work from the activity. The selection of NCV clips for an artifact-based reflective interview is a process based on two goals: the investigation of the connection between the MII activity design and student pragmatic epistemology, and the identification of student pragmatic epistemological resources.

In order to identify the connection between MII activity design and student pragmatic epistemology, the selection of NCV clips for interviewing needs to be based on the MII design. For example, every MII Model Development activity includes variable identification, which is designed to establish an open and constructive approach to achieving the target model; therefore, I look for video that encompasses some of these discussions so that I can ask about their approach to this section. To accomplish this I start with the NCV description and code the group activity based on where they are in the MII activity. The explicit design of the activity makes this process somewhat straightforward; however, there are a few common, but peripheral, factors that affect student engagement, which I also identify. For example, TA interactions are coded as such, as are interactions with other groups, and off-topic discussions. These peripheral codes are somewhat similar to epistemological framing behavioral codes; but, because the major focus is on the MII design, I focus on the divergence of behavior away from the activity instead of following epistemological frame coding guidelines explicitly (Scherr R. E., 2009). This approach leads to a relatively consistent set of NCV clip artifacts across the interviews, with the main selections being: initial exploration of setup, variable identification, experiment planning, data taking, and data analysis. Focusing the artifacts in this way is a key moment in the hybridization of Grounded Theory with my research goals. Directed data selection is traditionally done based on what is being found in the data (Schram, 2006; Charmaz, 2006); whereas, my data selection is based on the context within which the data is taken, the MII activities. On the other hand, my selection of certain artifacts based on epistemological salience such as group discussions, or spoken reflections, opens up my research to the type of insight that Grounded Theory is designed to uncover (Schram, 2006).

Preparing Artifact-Based Reflective Interviews

Once areas of interest have been identified as described, I again use Transana to create a second avenue for accessing the video based on the clip selections. I access the video through the descriptive account that I based my selections on, and in the second document, select the video that corresponds to the clip artifact of interest. Within this selection, I jot down the key reasons for choosing the clip, and formulate one or more questions that I would like to ask participants during the interview. These reasons and questions are essential for the Inter Rater Reliability metric later, and are of a relatively limited variety. For example, clip selections focus on students working with computer probes or measuring tools, generating explanations, and making decisions about what to write down; the questions written for these clips target how students make sense of what to measure and what the values mean, what their explanations are founded upon or the role of a partner's explanation, and what the motivation for recording their ideas is.

In constructing these questions I attempt to focus on an epistemological aspect of the clip. For instance, if the group latches on to an idea that one of the participants brings forward, I might ask the participant that came up with it where that idea came from. This question maintains an open-ended nature focused on an epistemological target, the source of their idea, which is the base of their knowledge claim. In circumstances where I will be interviewing multiple group members using the same clips, I prepare different questions for the different individuals based on their roles in the interaction. For example, the same clip where I ask one participant where their idea came from, I might ask one of their partners how they reacted to, engaged with, or evaluated the idea that was put forth. These questions target the role of their partner's ideas in their own engagement of the activity.

With the questions prepared, the final step is to organize the interview sequencing. Initially, I structure the interview in the same order as the activity itself: starting with their exploration, and ending with their data analysis and discussion. However, interviews are interactions with the goals of establishing rapport and working towards a good interview experience for both the participant and interviewer. In light of these goals, I sometimes jump around to clips that are related to ideas that the participant is bringing up. This technique is used to try to build depth of understanding on specific topics when the opportunity arises (Seidman, 2006).

Performing Artifact-Based Reflective Interviews

The interviews themselves are performed in the group study room of the Physics Library. This room has a television with speakers, which allows both the participant and myself to watch the video clips comfortably, and a large table, which gives the participant room to look at both a printed copy of the lab activity and their group's work. The interviews are one-hour in length, and follow a semi-structured protocol. Before the interview begins, I deliver another informed consent speech similar to the one prefacing the NCV data collection.

Once the interview begins the organization around the playing of a clip is as follows: a clip is introduced by myself describing where in the activity the clip is pulled from, and giving a general overview of what they will see; then, I play and watch the clip; after the clip is played, I ask one of the prepared questions grounded in the clip; depending on how the participant responds, either a follow-up clarification question is asked, another prepared question based on the clip is asked, or the process iterates with a new clip being introduced. As mentioned in the last section, the prepared order of the interview may deviate depending on the participant responses. Most interviews end with a question or two that targets the activity as a whole, or the notion of "completing" the activity. These questions are not grounded in a particular clip or student response, but rather the entirety of the activity.

Transcribing ABRIs

Transcribing the interviews is performed with Transana. Each interview is transcribed with the focus on narrative responses, which means that extra efforts are not taken to attend to para-verbal and non-verbal cues. This choice is made because the focus of this methodology is on informing the interpretation of the activity in the NCV, not the interview response itself. However, there are times that students' non-verbal communication is notated, usually when it is an essential aspect of the narrative. For example, when a participant says "like this" and makes a hand motion, that hand motion is recorded. By explicitly not transcribing inflection I am backing away from a fine-grained analysis of the interview, and this may cause me to miss some insights about the participants' epistemologies. These insights may be valuable, but are seated in the context of the interview and not the NCV, where my analysis is focused.

Coding ABRIs for Pragmatic Epistemological Resource Application

Once the interviews are transcribed into Transana, the focus of my efforts shifts to analyzing and interpreting the epistemological impact of the interviews to understanding student pragmatic epistemology. Working with Transana requires the analysis to be based on applying a keyword coding to "clips," selections of the interview transcript that are correlated to the interview video. The choice of what to select for a clip is similar to the way that I described the interview process itself: each NCV clip along with the questions and responses that follow are selected into a large "sequence clip;" each question and response based on the NCV clip is selected into a smaller "question-response clip;" and finally, each participant response is selected into a "response clip" by itself. This provides a nested structure for applying keywords to these analytical clips, Figure 4-1.

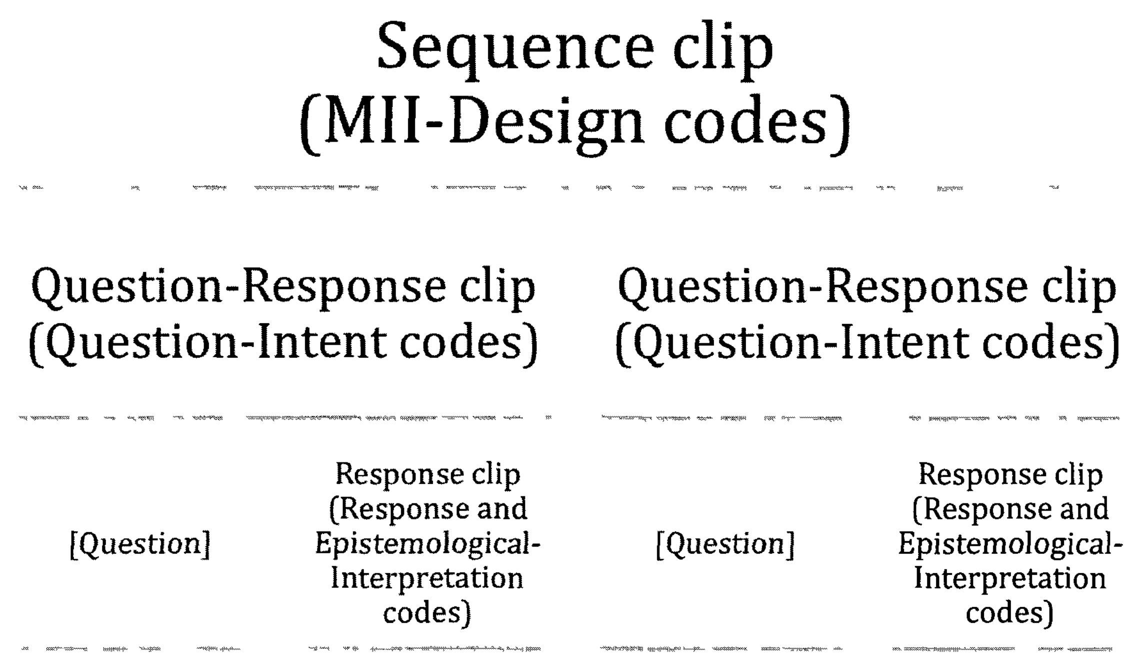

Figure 4-1: The nested structure of analytical clipping in ABRI analysis.

The keyword organization in Transana is such that each keyword belongs to a keyword group, and each clip can have any number of keywords applied to it from any number of keyword groups. For my analysis I created four main keyword groups: MII-Design Codes, Question-Intent Codes, Response Codes, and Epistemological-Interpretation Codes. MII-Design Codes are applied to the sequence clips based on the NCV clip, such that an umbrella MII context is set for the clips nested within it. Question-Intent Codes are applied to each question-response clip based on the epistemological intent of the question asked of the participant. Response Codes and Epistemological-Interpretation Codes are applied to response clips; Response Codes describe key aspects of the participant statements, while Epistemological-Interpretation Codes are applied based on my interpretation of the participant response. The Epistemological-Intent Codes are essentially first order claims of pragmatic epistemological resources. There is a fifth keyword group named Context Codes, which I use to identify key aspects of the context that I don't believe fit in the MII-Design Codes category. Further discussion of the application of these codes is reserved for Chapter 5, where I will discuss the results of this research.

Analyzing Pragmatic Epistemological Codes

The analysis of the code applications comes in two flavors: qualitative code reduction, and quantitative code correlation.

Qualitative code reduction follows the principle of constant comparison from Grounded Theory mentioned earlier. The number of unique codes applied to the interviews grows during the initial interview analyses; then, the number levels off as the keywords defined saturate the space of responses; finally, the number is reduced upon reflection, and reduction of redundant codes into single codes.

Quantitative code correlation is done via a simple algorithm implemented in a PERL script. The algorithm operates on a "Clip Keyword Data Export" from Transana, which is a tab-delimited file that contains a row for each clip within an interview. The column structure for these rows begins with the essential information about the clip, and then is followed by a column for each defined keyword. Each row then contains a clip's essential information followed by either a true or false value for each defined keyword based on whether or not it is applied to that clip. The goal of the algorithm is to identify every keyword that is applied concurrently through the nested structure of the clips. For example, the keywords applied to a response clip are associated with the keywords applied to the question-response clip and sequence clip within which the response clip is nested. The algorithm is as follows:

1) For each clip row:
    a. Find all keywords applied to this clip.
    b. Find all clips that overlap this clip (see Figure 4-1).
    c. For each overlapping clip:
        i. Find all keywords applied to this clip.
        ii. Increase the correlation value between each keyword applied to this clip and each keyword applied to the original clip.

The result of this algorithm is a symmetric correlation table with a row and column for each keyword defined in the system. From this table the frequency of a single keyword being applied is found on the diagonal, and the off-diagonal values represent the number of times the keywords are applied at the same time interval during the interview.

These two analyses each target one of the research goals of this study. The qualitative code reduction gives rise to a final set of Epistemological-Interpretation Codes, which is a limited catalog of pragmatic epistemological resources identified through this study. The quantitative code correlation between MII-Design Codes and Epistemological-Interpretation Codes is the basis evidence-based claims about the pragmatic epistemologies of students during MII Model Development Activities.

Inter-Rater Reliability of the Artifact-Based Reflective Interview Protocol

In this section I will describe the design and implementation of an inter-rater reliability measure for the creation of Artifact-Based Reflective Interview Protocols. As described earlier, this reliability measure is designed to explore the question of whether independent researchers, with a common set of guidelines, can select similar clips of NCV video for similar reasons, and propose similar questions to be asked in an interview. This measure is an important first step for showing that this methodology could be replicated in studies performed by more than one researcher.

Defining Inter-Rater Reliability

As it is practiced throughout the PER literature, inter-rater reliability (IRR) measures whether or not a research practice can be replicated among researchers, usually within the same research group (Scherr R. E., 2009). The standard approach to IRR has five steps: 1) a research practice is defined on an initial set of data by one or more researchers; 2) this definition is communicated to researchers that have not worked on the data; 3) two or more researchers implement the practice independently on a new set of data; 4) the initial implementations are compared; and finally, 5) the discrepancies in the implementations are discussed allowing researchers to come to agreement where there is initial disagreement resulting in a final measure of IRR (Scherr & Hammer, 2009).

The key concerns in implementing this algorithm for IRR are steps two and five. In step two, the researchers that developed the practice must communicate the practice in an efficient and effective manner; this is sometimes done using a data set for training, where researchers may enter a master-apprentice power relationship. In step five, the discussion of initial disagreements and transitions to agreements is a process that has the potential to degrade the measure. If one researcher consistently yields to the other because of an underlying power-dynamic, then the measure degrades.

The ABRIP IRR Measure

In this study the IRR measure covers two major steps of my research practice: the selection of NCV clips, and the preparation of questions to be asked concerning those clips. For these research practices, I play the role of the developing practitioner, and Dr. Meredith plays the role of the independent practitioner.

In step one of the IRR, the development of the research practice, I refer to the previous sections of this chapter, and will not recount them here.

Step two of the IRR requires describing the research practice to the independent practitioner. Dr. Meredith, as my advisor for the duration of this research, is aware of my interest in pragmatic epistemology, and as the instructor for the physics 401/402 courses during my research, is aware of the structure of the MII activities. However, she did not have privileged access to my development of the interview protocols before the IRR process, and as such is a reasonable candidate for the independent practitioner. The key aspects of the protocol that were described are identical to those laid out in the section of this chapter covering clip selection.

Step three of the IRR requires each researcher to produce the following: the start and end times of their NCV clip selections, the reasons for selecting that section of NCV, and one or more epistemologically oriented questions to be asked of the participants based on the NCV clip.

Clip #	Clip Selection Time	Reasoning CWS	Reasoning DCM
1	16:30.5 – 19:10.6	Exploring equipment; discussing resistor vs capacitor; do wire colors matter; does order of circuit matter	Focus on color of wire as possible issue
2	20:41.4 – 20:57.5	Failed current probing; reaction to TA giving information	
3	24:01.0 – 24:56.0	Discuss dead battery; equipment troubleshooting; confirming what told / variation; lead to TA help	(20:58 through 24:06 +) interaction with equipment and computer; confusion; playing around; trying to make sense
4	27:20 – 27:55		Sarah checks leads / verifies TA information
5	28:33.1 – 29:34.7	Charge model; confusion and skipping;	(28:51 – 29:30) Reversal of signs from worksheet; skip it (charge model)
6	30:16.3 – 31:35.6	ID Variables prompt; use of equipment and handout to determine experiment?; "modeling setup"	(29:30-34:44) interaction with sheet; ID variables; use of blanks

Table 4-1: Table comparing clip selection and reason for selection between researchers.

The clip selections begin with reading through the description of the NCV. For example, clip 6 is identified based on the description "Read independent/dependent question. Identify resistors as independent as being changed. Mention both current and voltage as dependent. Mention only having three resistors, believe that they need four, based on what materials were on the table when they arrived." This description indicates that they are in the variable identification section of the activity, and are working out which variables are dependent or independent. This is an important knowledge claim in the scheme of the activity, because it sets the stage for the rest of their experiment. It is also interesting because they must justify their choices, and the identification of variable dependence often appears to be determined by the multiplicity of the equipment at a lab table; however, in order to identify the way students treat this knowledge claim, they are explicitly shown their decision process and asked how they came to their decision. These thoughts are reflected in the reasoning CWS column of Table 4-1.

I then compared the selections, reasoning, and questions without the input of Dr. Meredith to compute initial IRR values of following measures for each clip selection. Do the clip selections overlap with any selections by the other researcher? If so, are the reasons for selection based on the same key aspects of the clip? If so, do the questions that are proposed share a common purpose? Of the clip selections shown in Table 4-1 the overlap of clip selection times is clear in 1,3,5, and 6; the reason for selecting these clips is also considered similar. For clips 2 and 4, the overlap in time and reasoning is not evident, and these clips do not contribute to successful reliability measures. In terms of question intent matches, the results are identical. For example, Dr. Meredith posits the question "Do you decide on the independent variable by the sheet or by the equipment? Which seems more reliable?" for clip 6, while I ask the following questions of the three participants Craig, Sarah, and Rachel respectively: "You're identifying the dependence of variables, can you walk me through how you figure that part out?", "How do you decide what's independent and dependent?", and "How did you determine which thing you would measure as response? How did you choose your dependent?" These questions are determined to have the same intent, to get the participant to explain how they approach the dependence of variables as a piece of knowledge moving forward with the experiment.

Step five of the IRR process is a joint venture between Dr. Meredith and myself, to identify the perceived gaps between our decisions, and to discuss our stances, and to determine if the perceived gaps are true discrepancies in our practice. This process is a lengthy iterative discussion that takes on each discrepancy anew, and requires clear articulation of not just our choices, but why we made them. For instance, we find that separating out the intent of each question, that which we hoped to uncover through the question, from our wording of the question give us better insight into whether we are in agreement. It is in this discussion that power relationships within research groups are dangerous, as one member can bully others into agreement; however, as the "apprentice" in this study is also the advisor, the power relationships are relatively balanced and were not an issue. In Table 4-1 the clips that were in question before, 2 and 4, are discussed further. Clip 2 is associated with clip 3 in one of the interview protocols (both clips are played together) resulting in the same questions being asked. This overlap in question intent is not counted towards the sum because it is not an overlap in clip selection. Clip 4 on the other hand is chosen by DCM due to the student TA interaction, which is covered in Clip 3 of CWS's selection. This leads to the clip considered a selection overlap post-discussion, and the matches in reasoning and question intents are also counted.

Results of the IRR

We performed the above IRR on two NCV episodes. We treated the first episode as a training data set, and only analyzed a portion of the two-hour video. In this process we found that epistemological notions such as "students appear confused" could be too interpretive to be reliable between researchers, and we reiterated the need to focus on concrete actions and cues from the activity guide.

Once the training session was over, we chose a NCV where I had performed interviews with all-three group members on which to perform the IRR. This choice allowed Dr. Meredith to specifically identify which participant she would like to ask a question of, or to pose multiple questions of different individuals, which is comparable to my process of preparing for three independent interviews.

The results of steps four and five are shown in Table 4-2. The "Selection Reason Matches" metric in step four is calculated as the ratio of the number of clips for which the reason selected matched to the number of clips for which the selected NCV time overlapped. In step five however, the total number of overlapping clips increases by 5 due to discussions that indicated the selection of NCV for the clips was in proximity (not overlapping), and where both practitioners agree that they were interested in the NCV for the same reasons. The "Question Intent Matches" metrics are the ratio of the number of clips where the indicated question intent matched to the number of clips where the selection reason matched. Increases from step 4 to step 5 are again due to the same changes mentioned for the "Selection Reason Matches."

Metric	Pre-Discussion (Step 4)	Post-Discussion (Step 5)
Selection Reason Matches	85% (11/13)	94% (17/18)
Question Intent Matches (All)	82% (9/11)	82% (14/17)
Question Intent Matches (Any)	91% (10/11)	96% (16/17)

Table 4-2: Inter Rater Reliability Results.

From these results, I claim that it would be reasonable to aggregate data from interview protocols developed by Dr. Meredith or myself. In a large-scale qualitative study practical issues such as this become important; this result sets a precedent for evaluating an ABRIP for data aggregation, and is the first step to moving classroom video analysis beyond behavioral coding.

CHAPTER 5

PRAGMATIC EPISTEMOLOGY

In this chapter I will discuss the results of my research into student pragmatic epistemology. First, I will describe how the Artifact Based Reflective Interview coding gives rise to a small set of large grain sized epistemological aspects based on the epistemological questions which are motivated by my understanding of epistemological theory. The epistemological aspects are populated by the small grain sized resources identified from the privileged interview data, which has emergent structures that filter up to match the epistemological aspect organization. Then, I will describe some of the essential codes that underlie these aspects and how they fit with the larger scope of personal epistemology. Finally, I will discuss the proof of concept for assessing the MII Model Development activities through the correlation between codes for a sample of the interview participants.

Organizing Codes to Identify Epistemological Aspects

I begin this section by discussing the means through which qualitative epistemological interpretation codes are initially applied. Then, I explain the categorization and partial reduction of these codes into epistemological aspect categories, as described in Chapter 3. These categories are partially informed by the theoretical structure of epistemology, which drives interview questions, but populated with pragmatic epistemological codes which are generated from the data as per Grounded

Theory's constant comparison mehod. The combination of these two influences informs the middle levels of the categories seen in this chapter.

Developing Epistemological Interpretation Codes

The process for developing epistemological interpretation codes is briefly discussed in Chapter 4; however, the detail of this process is fundamental to the claims made herein. In total 16 interviews were conducted (with 1 corrupted by technical difficulties), spanning 3 semesters from Spring 2009 through Spring 2010. These interviews cover 5 different MII activities, and 10 different lab groups (three groups with two participants, one group with three, and six single participant groups, one of which was interviewed twice). The majority of the data presented here comes from one of these groups with two participants. The interview process as described in Chapter 4 gives rise to participant narrative in response to the contextualized questions of the interview itself. The narratives are fairly unique to the individual participant; however, the questions and contexts are relatively consistent, as per the protocol construction guidelines discussed. Participant responses to the protocol-based questions vary greatly in length and detail, but the analysis performed in this research applies codes to the responses as a single analytical clip. Due to this choice in analytical grain size, many aspects of a single narrative response are coded within the same analytical clip, the response clip. There major effect of this is that a single response clip may be coded with many seemingly disparate descriptors. There are also two fundamental issues that affect the completeness of a resource-based analysis such as this. First, resources in use may not always be apparent; certainly they are not all explicitly discussed by individuals using them, thus preventing complete identification of active resources. Secondly, the volume of narrative combined with the fact that the codes are identified and applied by a single researcher making judgments and interpretations in a finite amount of time, allows ample room for details of pragmatic epistemology to escape description. However, this analysis seeks to illustrate the depth of data validity and potential impact of the artifact-based reflective interview protocols for epistemological investigations, as such the analysis of this data is not intended to be a complete description of student pragmatic epistemology.

In coding the response clips in this fashion there are two major keyword groups applied: the response codes, and the epistemological-interpretation codes. The goal of having these two groups is to give a mechanism for transitioning from the more open response codes to more focused epistemological interpretation codes through the first few interviews, a sample of these codes can be found in the appendix. To illustrate this process I present the sequence of data leading to the analysis of a single question and response. The data presented here comes from a lab activity where students are exploring the behavior of an elastic string under tension. The goal of the activity is to model the deformation property of the material that makes up the string, and not just the sample of string itself. This question follows a clip of NCV where the group members are discussing what to measure, here is my description of the NCV:

> (0:14:02.6) Immediately one person suggests the stretch of the string, other member questions if the string is stretchy. Agree on where to measure the string. Record their choices. Question if they should record the distance stretched or the length of the string itself, note that distance stretched involves a subtraction, an extra step. Ask if they should be recording information. Recognize that they are just observing at this point.
>
> (0:15:56.9)

The description indicates that the students are reasoning about what they will need to be measuring, but fall short of defining variables, referring to the idea that they are only making observations at this point in the activity. Two clips are selected from this chunk of the NCV and played together in the interview. The first question asked focuses on the purpose of the discussion about variable identification, which leads to a strong narrative response, this excerpt spans lines 135 to 147 of the complete transcript in the appendix:

> I: Alright so, can you tell me a little bit about um... what you are trying to get at or get out of those conversations?
>
> Julia: So, we were trying to figure out what we were going to be measuring, what would be the constant variables, versus like the- what we were changing. And um, we knew that we had to find out something about the material, in the end, that like all of our data was going to tell us something. So, we knew that the length was changing and we knew it was because of the force, and the weight we were adding. But um, we weren't sure at that point what that told us about the string, we just knew like... um whenever we added weight- or added force to the string it would stretch, and we had to measure that, and we would be um comparing it to something else to find out a property of the string that the lab was getting to.

The coding process goes as shown in the tables below: (1) initially generate and apply response codes to an interview transcript based on the coherent phrasing students use, these codes break down the student response into several manageable chunks; (2) re-analyze the transcript making epistemological interpretations, develop and apply epistemological-interpretation codes that compliment the epistemologically relevant response codes; (3) evaluate the coordination between the transcript, response codes, and the epistemological-interpretation codes, generate heuristics for identifying epistemological-interpretation directly from the transcript and identify gaps in epistemological-interpretation codes compared to response codes.

Participant Statement	Response Codes
"We were trying to figure out what we were going to be measuring"	Deciding-through-discussion Defining-variables
"What would be the constant variable versus like the- what we were changing"	Defining-variables Experiment-design
"we knew that we had to find out something about the material, in the end,"	Goal-oriented-model
"We knew that the length was changing and we knew it was because of the force, and the weight we were adding."	Cause-effect-knowledge-from-observation
"what that told us about the string"	Goal-oriented-model
"whenever we added weight- or added force to the string it would stretch, and we had to measure that,"	Measure-effect
"we would be comparing it to something else to find out a property of the string that the lab was getting to."	Comparing-to-create-knowledge Goal-oriented-model

Table 5-1: Response codes applied to participant responses.

The response codes are given short names for ease of use; however, each code is accompanied by a one-sentence explanation of what I intended to contain within the code when it was originally defined for its first application. These definitions help me evaluate whether or not a new code needs to be created, or if the student response falls within the definition of an extant code.

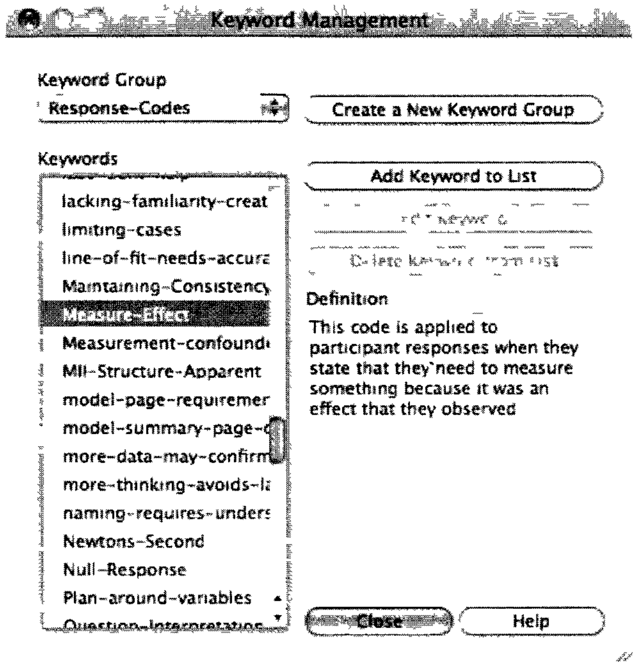

Figure 5-1: Definitions of codes elaborate on simplistic names.

This example shows the connection of the response and epistemological interpretation codes to the narrative itself. A few things to notice about this example are the following: the mention of data telling the students something was missed in the response coding, but picked up on explicitly in the epistemological interpretation; the combination of theoretical understanding and physical observation with regard to the string stretching in response to the weight being added is epistemologically interpreted both ways concurrently, meaning that two seemingly opposing knowledge-source-mechanism resources are being activated in concert; the uncertainty expressed by the student has an "at this point" temporal indication with it, but there is also an expectation that the activity's goal is to clarify this confusion. The third step in the coding process is best understood as a "checking your answer" step. Once I have applied both sets of codes, I read back through the transcript, the response codes, and the epistemological-interpretation codes, in an attempt to identify things I missed on the first pass. This speaks directly to the statements I made earlier regarding the lack of completeness of a resource-based model of data, in that the best I can do is to look back at the data with an eye for gaps. In terms of coming up with heuristics for identifying pragmatic epistemological resources, this happens both through the creation of definitions as seen in Figure 5-1 and through the identification of the emergent organizational structures in the epistemological-interpretation codes discussed in the next section.

Participant Statement	Epistemological-Interpretation-Code
"We were trying to figure out what we were going to be measuring"	Kn-form-decision
"what would be the constant variables, versus like the- what we were changing."	Kn-form-decision
"we knew that we had to find out something about the material, in the end,"	Kn-form-expectation Kn-form-part-for-whole
"all of our data was going to tell us something"	Kn-justification-measurement/data Kn-source-data
"we knew that the length was changing"	Kn-by-construction-physical-observation
"we knew it was because of the force, and the weight we were adding."	Kn-by-construction-theoretical-concept
"we weren't sure at that point"	Kn-stability-tenuous
"what that told us about the string"	Kn-form-expectation
"whenever we added weight- or added force to the string it would stretch, and we had to measure that."	Kn-by-construction-theoretical-concept Kn-by-construction-physical-observation
"we would be comparing it to something else to find out a property of the material that the lab was getting to."	Kn-by-construction-comparison Kn-form-part-for-whole Kn-form-expectation

Table 5-2: Epistemological-Interpretation codes applied to participant responses.

It is the degree of situated articulate detail in the student narratives that comprise the argument for this data's validity for describing student pragmatic epistemology.

Identifying Epistemological Aspects

Once the process of applying both codes to a few interviews is complete, the major development of epistemological-interpretation codes is over by virtue of the explosive growth of the codes in the initial analyses and overlap between interviews. The epistemological-interpretation codes at this point have grown out of contextualized responses, are focused explicitly on interpreting student responses in epistemological terms, and avoid over-reach by maintaining the role of response codes as describing non-epistemological aspects of student responses. For example, the response code "AG-easier-on-own" is applied when students are reflecting on the activity guide, and indicates that they would rather just do the activity without the guide, on their own. This code does not have a straightforward epistemological interpretation; however, it is a coherent statement about their ideas regarding the activity. As an individual researcher evaluating student responses, I am drawn to describe everything that I see in the data. By allowing myself to code the responses openly at first and then to re-focus the analysis on epistemological interpretation, I am able to hone my interpretive attention away from non-epistemological aspects with an explicit mechanism. At the same time, the epistemological aspects as described in Chapter 3 are embedded in my interpretation, and each epistemological interpretation code has a term built into its definition that identifies the target epistemological aspect.

For the remaining interviews, I rely on my initial self-training to avoid over-reaching and apply mostly epistemological-interpretation codes directly on the first pass.

There is no point at which I expect to have created every epistemological-interpretation code needed to describe any pragmatic epistemology; however, after a few interviews, the epistemological-interpretation codes seem to have a clear organizational structure that I describe as epistemological aspects. These aspects are large-scale organizational structures that help integrate my research results with the overarching body of epistemological research. The top levels of these come from my knowledge of epistemological theory, and played a significant role in driving the question-intent codes that describe my interview protocols. The lowest level of these organizational structures are the epistemological-interpretation codes themselves, that are directly interpreted from the interview transcripts. The middle layers of the organizational structure connect the two extremes by seeking emergent structure through constant comparison qualitative analysis techniques, looking for themes that emerge from the finest grain size data, the epistemological-interpretation codes. For example, there are several instances where the epistemological-interpretation codes describe an attribute of the knowledge claim, such as the familiarity of an idea. At first this idea seems to fall outside of the epistemological aspect "stability of knowledge" as it does not explicitly describe a degree of certainty. However, familiarity might define a stage in developing trust, and trust of knowledge underlies stability or certainty. By reflecting on the organization of codes in this manner, we can avoid an explosion of epistemological aspects, while making these aspects more robust.

Composition of Epistemological Aspects

The way in which the epistemological-interpretation codes combined with my prior theoretical orientation gives rise to the epistemological aspect categories is not trivial. Articulating this process may not be the best course of action; however, describing the constituents of the epistemological aspects, and how they are associated together will strengthen my argument for their identification as belonging to a coherent epistemological aspect.

Epistemological Aspect – Source

The source of knowledge has two major parts: the source-object, person or artifact, that is the physical source of the knowledge; and the source-mechanism, that is the way the knowledge came to the individual from the source-object. These two subcategories are still coming mostly from theoretical considerations; however, they align with several epistemological-interpretation codes, giving them credence.

Source-objects fall into two distinct categories, the self, or outside the self. This distinction clarifies the notion that knowledge can either be created by an individual, or be transferred from an outside presence. The self as a source of knowledge aligns with educational reform described as constructivist, student-centered, and active-learning. These require that the learner be an essential player in the learning process. Conversely, sources of knowledge outside the self align with the notion of knowledge being transmitted from an authoritative source and received by a welcoming individual. Source-mechanisms range from simple to the more complex.

There are two simple mechanisms that describe some form of transmission and reception: telling, from an outside source with some level of embodied or expressed authority, and recall, from the inside source with some level of implicit authority. On the other hand, there are several more complex mechanisms by which individuals create or construct knowledge on their own. It is these that illuminate the sorts of new epistemological resources beyond what has previously been identified.

Through the interviews in this research, I have evidence of several concrete mechanisms for knowledge creation. These mechanisms may be chosen depending on the target knowledge form, or the available information, and they are akin to the epistemic games described in Chapter 3. Simple knowledge claims can be made based on concrete observations, such adding items to a list. As the complexity of the knowledge increases, so do the mechanisms for constructing it; from the example above, students utilize comparison, physical observation, and application of theoretical concepts throughout the MII Model Development activities as ways of constructing new knowledge.

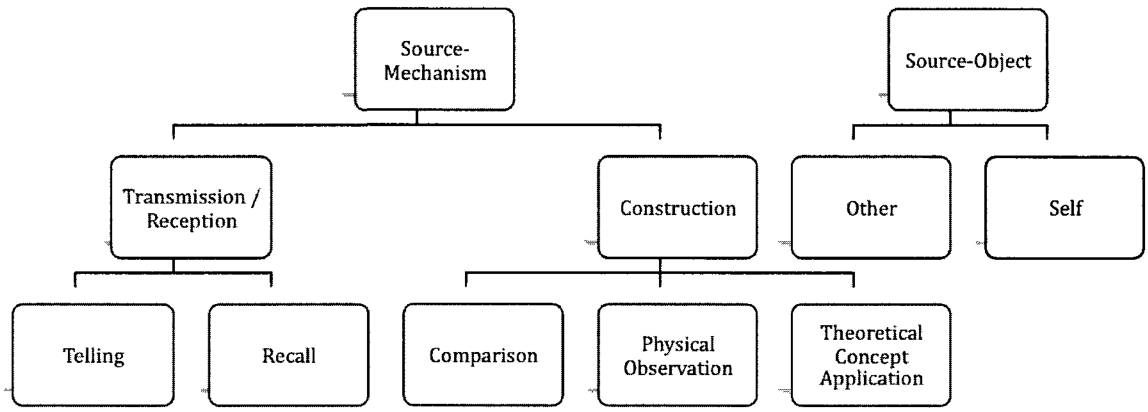

Figure 5-2: Source, as an epistemological utility with both mechanism and object as attributes.

Epistemological Aspect – Utility

An important epistemological aspect that is not discussed in other studies is the utility of knowledge. In this study I find that students have specific purposes or motivations in mind as they work through the activity. Their approaches to prompts may be affected by the ways in which they expect to use their responses or knowledge at a later time.

One essential dimension of this utility is just this temporal notion: do they expect to use the ideas they are generating in response to a prompt beyond the prompt itself? The data shows that students see various degrees of temporal utility depending on the prompt, and the individual. The key scales that I see for this in the data are: knowledge is only useful to answer this prompt, knowledge is only useful in this activity, knowledge is only useful in this course, and knowledge is useful beyond this course.

For example, students explicitly write out their steps before engaging in the experiment itself; however, there are at least two major distinctions between how they approach this task. One approach is that students see the written account as required only, and therefore engage in a purely "completing the activity" type of behavior. Some students also regard their written plan, the knowledge of what they are about to do and how they are about to do it, as essential for checking their actions during the experiment. Perhaps because they perceive this later use for the plan, they work more diligently to understand how they should execute it, and attend to this more later.

This underlying "will be important later" theme comes into play with ideas that are viewed as central or anchoring, ideas that may be important for future decisions, and sometimes purely as a possibility of future use. The important thing to take away from the temporal dimension here, is that some students are engaging with the notion that the ideas they develop in the activity are not only useful in the moment that they create them, which is an underlying notion about the knowledge we teach, that we as educators hope to instill in our students.

The temporal dimension is integral to each pragmatic epistemological resource identified within the utility aspect; however, beyond the temporal dimension lie the specific uses that students see for their knowledge claims. A sample of these is shown in Figure 5-. One of the most important ideas that falls under utility in this analysis is the ability for knowledge claims to aid in the checking for consistency in later work. This idea is discussed in many of the interviews.

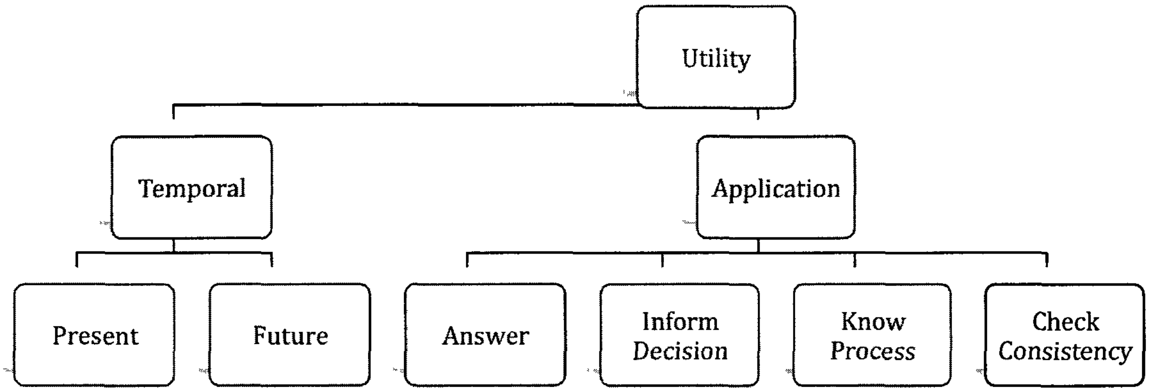

Figure 5-3: Utility as an epistemological aspect comprised of a temporal attribute and a concrete application.

<u>Epistemological Aspect – Stability</u>

The stability or certainty of knowledge in pragmatic epistemology is related to, but not the same as plasticity of resources discussed in Sayre's dissertation. In the context of this study, resources that describe the stability epistemological aspect are describing a student view of a particular knowledge claim, not the resource itself as stable or unstable for the individual student. In terms of the stability of students' knowledge claims I find three major distinctions in the data: knowledge is certain, true or false; knowledge is scoped, it has a distinct range of validity; and knowledge is uncertain, there is no confidence in claims of validity.

The first of these categories, knowledge is certain, is easily understood and seen frequently with knowledge coming from authority, as statements from authority are taken to be true. Curiously, this notion may collide with scoped validity in instances where authoritative sources describe the knowledge they are conveying as being scoped. The third category, knowledge being uncertain is also less complex, and applies when students are still confused or lacking confidence in their ideas. The notion of confusion and uncertainty is often expressed as difficulty with material in the course, or the connections between ideas in the laboratory context and the course itself. Finally, the idea that knowledge may apply only within a certain domain, scoped, is an essential aspect of modeling theory, and its presence in the data is a strong indicator that the essentials of modeling are at least partially transcending instruction.

Beyond these three categories, the stability of knowledge must have some form of justification, and this falls under the same aspect. For example, knowledge claims can be justified by invoking the authority of an individual, or an equation, by referring to a mechanism, or explicitly through reference to observations or data.

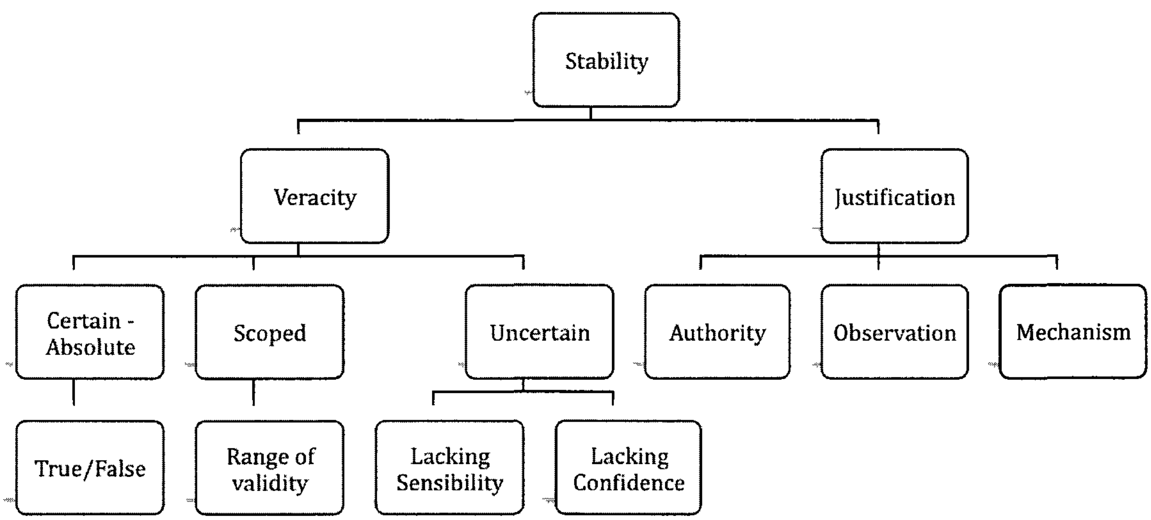

Figure 5-4: Stability, an epistemological aspect with attributes veracity & justification.

Epistemological Aspect - Structure

The structure aspect of pragmatic epistemological resources, like the previous aspects, has a complex substructure itself. The persistent dimension within the structure aspect is that of knowledge sophistication, is knowledge interconnected or isolated. This dimension compliments the various types of knowledge described as epistemic forms in Chapter 3.

The sophistication of knowledge is a property that can be defined for any epistemic form. For example, a particular fact may be viewed as interconnected or isolated from other facts being discussed. However, the level of sophistication that is indicated in the data goes beyond simple interconnectedness and adds dependency to this network structure. For example, students will comment in interviews that at the time they were working in the activity they did not have the requisite understanding of forces to build into the idea of stress, force per unit area. In terms of epistemic forms, I identify the multiple representations used in modeling, while also attending to intermediary events that play a role in the process, such as decisions.

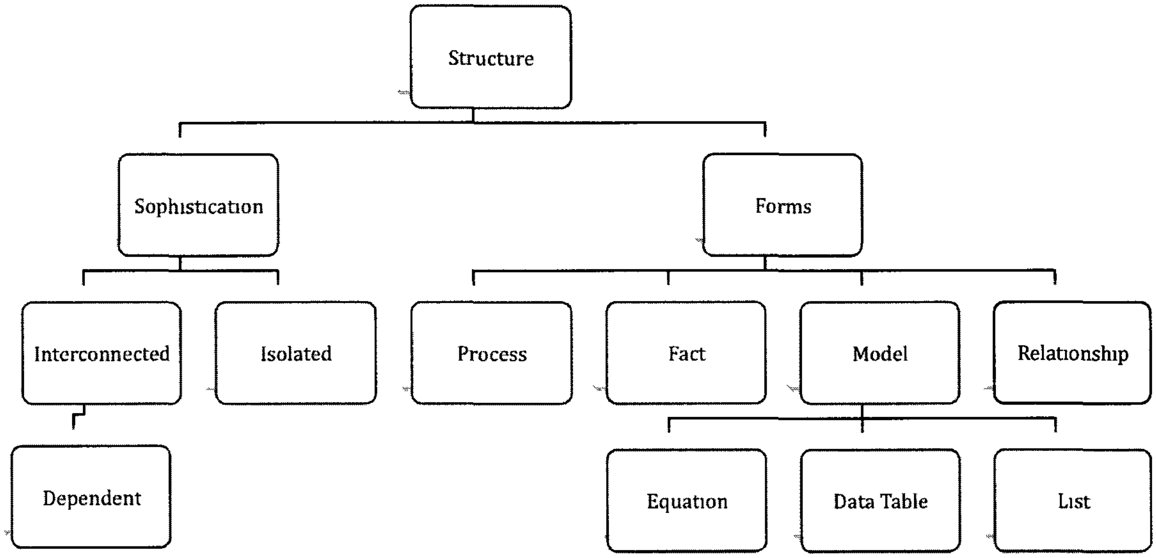

Figure 5-5: Structure, as an epistemological aspect with attributes form, and sophistication.

MII Model Development Activity Analysis

In this section I present the correlation of epistemological-interpretation codes to MII-Design codes as described in Chapter 4. This is the proof of concept for epistemological assessment of a curriculum using data achieved through an Artifact-Based Reflective Interview methodology. The data for this analysis comes from three semesters of PHYS 401/402, encompassing 2 different versions of MII activities. These versions are similar to each other and the final version. Each MII Model Development activity section described in Chapter 2, except for the "Model Presentation and Peer Evaluation" due to limited interview data, is presented with a table of the code correlations. To clarify, the major difference between the third and fourth versions of the MII activities lies in the organization of the initial stages of the activity. In MII v3, the stages proceed as "Prior Concepts and Models," "Qualitative Exploration," and

“Identification of Variables.” In MII v4, the “Qualitative Exploration” and “Identification of Variables” are combined under the heading “Preliminary Model.” The data is combined along these same lines. The individual table values represent the frequency of the epistemological-interpretation code applied within the indicated MII section. This is calculated as the number of response clips that have a particular epistemological-interpretation code applied divided by the number of response clips that fall within sequence clips covering the MII section. These tables are constructed based on interviews of two participants of the same group working together, using similar interview protocols. Code correlation frequencies that indicate a code was only applied once during the given MII Section are omitted.

Prior Concepts and Models

In the Prior Concepts and Models stage of MII activities, students are asked to investigate their apparatus and make connections between what they have in front of them and the models they have used in the past. In the ABRIs this stage of the activity is discussed in the very beginning, and is generally a short discussion of how students begin their activity.

The table below shows three perspectives on the epistemological-interpretation codes applied during discussions of prior models: the “MII : Prior-Concepts-Models” column represents code correlations when the interview sequence clip was specifically situated in that section of the activity; the “Connecting to Prior Models” column represents code correlations that include sequence clips where the clip includes talk about prior models, but not specifically in that section of the activity; and the “All Prior Models” combines both sets of clips. The data shows that in the explicit section of the activity, students indicate that they are only engaging in discussion because it is a part of the activity; however, in the non-structured references to prior models, they never make this claim.

Epistemological-Interpretation Code	MII : Prior-Concepts-Models	Connecting to Prior Models	All Prior Models
action-motivation-told-to	0.14	0.00	0.06
kn-by-recall	0.14	0.10	0.11
kn-by-construction-physical-observation	0.00	0.10	0.06
kn-quality-not-confident-with-content	0.07	0.10	0.09
kn-source-class	0.07	0.10	0.09
kn-type-decision	0.00	0.10	0.06
kn-type-definition	0.07	0.05	0.06
kn-use-discuss-with-partner	0.00	0.10	0.06

Table 5-3: Prior Concepts and Models correlation table.

Preliminary Model

In the Preliminary Model stage of MII activities, students make initial investigations of the physical phenomenon, and come up with a preliminary understanding of the system. The prompts encourage students to discuss their ideas, and do not indicate that there are correct responses.

The table below shows some indications that students are authentically basing their ideas off of what they see in front of them (kn-by-construction-physical-observation), and to some extent are remembering what they have seen elsewhere (kn-by-recall; kn-source-TA/Chemistry/Class). Furthermore, the students recognize that they are making decisions that affect the rest of their experiment and engage in discussions to make these decisions; these discussions often include references to consistency, change, and control, as justification for their ideas as students work out the behavior of the physical system. There are some indications that students are struggling with content, which is expected because these activities are meant to come before coverage in the rest of the course.

Epistemological-Interpretation Code	MII : Preliminary Model
action-motivation-told-to	0.07
action-purpose-theory-experiment-match	0.07
action-usefulness-computer-manipulation	0.04
kn-by-construction-math-calculation	0.04
kn-by-construction-physical-observation	0.15
kn-by-construction-theoretical-concept	0.04
kn-by-recall	0.09
kn-justification-change	0.07
kn-justification-control	0.04
kn-justification-observation	0.07
kn-quality-familiarity	0.04
kn-quality-not-confident-with-content	0.07
kn-source-activity-guide	0.04
kn-source-class	0.04
kn-type-decision	0.13
kn-type-expectation	0.09
kn-type-part-for-whole	0.11
kn-use-decisions	0.09
kn-use-discuss-with-partner	0.07
kn-what-they-want	0.04

Table 5-4: Preliminary Model correlation table.

Relationships and Planning Your Experiment

The Relationships and Planning Your Experiment stage of the MII activity focuses on making a concrete plan and following it through. The prompts encourage students to be specific and thorough in contemplating variables and procedures.

The table below shows three perspectives on student experimental design similar to what I described in Prior Concepts and Models: the “MII : Planning-Your-Experiment” column refers to sequence clips that come from that part of the activity itself, the

"Experiment Design" column captures sequence clips that involve aspects of experiment design that are not within the structure of the activity, and the "All Design" column combines these data. Overall, these students indicate that they think planning is valuable for making sure they are consistent as they proceed in the experiment. They also indicate that they are unsure of their decisions at this early stage, and their plan could be wrong; this aligns with the fact that they are not given a procedure, and are asked to create their own experiment.

Epistemological-Interpretation Code	MII : Planning-Your-Experiment	Experiment Design	All Design
kn-by-construction-math-calculation	0.00	0.10	0.05
kn-by-construction-physical-observation	0.00	0.15	0.07
kn-by-free-choice	0.05	0.05	0.05
kn-justification-consistency	0.10	0.10	0.10
kn-justification-measurement/data	0.05	0.05	0.05
kn-quality-can-be-wrong	0.10	0.00	0.05
kn-quality-data-sufficiency	0.10	0.05	0.07
kn-quality-should-make-sense	0.05	0.05	0.05
kn-source-data	0.05	0.05	0.05
kn-source-self	0.05	0.05	0.05
kn-type-decision	0.05	0.15	0.10
kn-type-part-for-whole	0.05	0.15	0.10
kn-type-plan	0.05	0.05	0.05
kn-use-get-grade	0.05	0.05	0.05
kn-use-potential	0.14	0.05	0.10
kn-use-refer-back-to	0.14	0.10	0.12
kn-use-write-it-down	0.05	0.05	0.05

Table 5-5: Relationships and Planning Your Experiment correlation table.

Execution and Data Collection

The Execution and Data Collection section of the MII activity focuses on the active nature of data collection. It asks students to keep track of troubleshooting issues and to pay attention to the data as it comes in.

Epistemological-Interpretation Code	MII-Section : Execute Experiment	Measurement
action-motivation-goal-of-activity	0.00	0.04
kn-by-construction	0.04	0.00
kn-by-construction-conditional-clause	0.04	0.04
kn-by-construction-math-calculation	0.00	0.04
kn-by-construction-physical-observation	0.04	0.15
kn-by-data-analysis	0.11	0.06
kn-by-discussion	0.07	0.04
kn-justification-change	0.13	0.17
kn-justification-consistency	0.27	0.19
kn-justification-control	0.07	0.12
kn-justification-measurement/data	0.07	0.08
kn-justification-observation	0.07	0.15
kn-quality-data-sufficiency	0.04	0.02
kn-quality-familiarity	0.02	0.04
kn-quality-has-prerequisites	0.02	0.04
kn-quality-should-make-sense	0.18	0.10
kn-quality-universal-independence	0.04	0.00
kn-quality-unsure	0.07	0.08
kn-source-data	0.11	0.04
kn-source-self	0.04	0.04
kn-type-big-picture	0.11	0.04
kn-type-decision	0.00	0.06
kn-type-expectation	0.13	0.13
kn-type-measurement	0.07	0.04
kn-type-part-for-whole	0.13	0.12
kn-type-process	0.04	0.04
kn-use-decisions	0.00	0.04
kn-use-refer-back-to	0.04	0.02

Table 5-6: Execution and Data Collection correlation table.

The table above shows two perspectives on student experimentation: the "MII-Section : Execute Experiment" column is comprised of sequence clips from that part of the activity, and the "Measurement" column represents all sequences where students take measurements. Since these sequences overlap, there is no combination of the data together. The strongest indicators here are that when not in the explicit section of the activity, students reason less quantitatively (kn-by-construction-physical-observation; kn-justification-observation). Control, consistency, and change come up again as the big three ways that students attend to the physical system and justify what they claim about it. There are two codes (kn-type-big-picture; kn-type-part-for-whole) that indicate students are making choices about what to pay attention to, and that they are comfortable using incomplete knowledge to model the physical system. This is a big thrust of Modeling and deserves further investigation.

Constructing Representations of Data

The Constructing Representations of Data section of the MII activity focuses on students building understanding on top of their data. The prompts for this section walk students through making multiple representations of their data, intending to reinforce the constructive nature of scientific models, and the use of data as justification.

Epistemological-Interpretation Code	MII-Section-Constructing-Representations
kn-by-comparison	0.07
kn-by-construction	0.09
kn-by-data-analysis	0.17
kn-by-summarizing	0.04
kn-by-think-of-everything	0.04
kn-justification-consistency	0.07
kn-justification-equation	0.04
kn-justification-measurement/data	0.04
kn-quality-familiarity	0.04
kn-quality-should-make-sense	0.15
kn-quality-universal-independence	0.04
kn-source-data	0.07
kn-source-discussion	0.04
kn-type-big-picture	0.22
kn-type-concept	0.09
kn-type-part-for-whole	0.20
kn-type-process	0.07
kn-type-verbalization	0.07

Table 5-7: Constructing Representations of Data correlation table.

The table above adds more strength to the claim that students are thinking about models as simplified representations of phenomena (kn-type-big-picture; kn-type-part-for-whole). It also shows that students consistently indicate their desire for their findings to make sense. This data in particular does not show indications that students are looking to their TAs for the answers; rather, they take significant responsibility for their understanding by founding their claims on their own data.

Closing Thoughts on Pragmatic Epistemology

The ABRI methodology is the solution that I developed to my ultimate research question, "How can we access privileged data from students on their approaches to learning activities that establishes the validity and reliability of that privileged data?" This essential question emerged from my original interests that sought to describe personal epistemology in a resources framework. Throughout this last chapter I have discussed analyzing codes that I applied to ABRIs as grounds for making claims about students' pragmatic epistemology. These claims attempt to address my original research questions about student pragmatic epistemology, and are entirely dependent on the impact of my ABRI methodology. The data that comes from these interviews is founded on my own interpretations, and I have tried to clearly identify my bias as an epistemological researcher. Further still, working within the resources perspective I state that it is impossible to give a complete description of what is going on in a single interaction, let alone many interviews worth. The amount of time and effort required to generate the codes applied to the data is not small, and mental exhaustion surely comes into play. I have tried to be consistent in applying codes to the concrete statements made by students, and to anchor their statements in the context of their natural classroom activity. Ultimately, the data presented here is only a glimpse of the richness that exists in the entirety of the interviews. Even with all of these issues at play, I still believe that the understanding of student pragmatic epistemology accessible through the methodology developed in this study is valid and reliable.

The ABRI protocols are the next step in developing valid and reliable descriptions of student pragmatic epistemology. The emergent organization of my codes into epistemological aspects aligns well with established work because it combines my understanding of epistemology through question creation. At the same time adds at least one more level of depth to existing epistemological resource theory by way of the privileged interview data anchored in classroom context. The articulation of epistemological resources beyond the level of "knowledge as constructed stuff" to "constructed by analogy" or "constructed by calculation" is a significant step forward for personal epistemology research and opens the door to more acute studies. The results presented here only skim the surface of the detail afforded by the ABRI methodology, and the detailed structures that lie beneath the surface only require more time to uncover.

At the end of the day my correlation of epistemological-interpretation codes to MII-design codes leaves much to be desired in terms of statistical fortitude, but it is a proof of concept, and as such requires further investigation. The ABRI methodology provides rich data, and this data has the potential to reveal the intricate detail of how students truly engage with scientific learning activities in academia and elsewhere.

Future Work

The ABRI protocols open up a plethora of new data with levels of detail that have not been investigated. A careful implementation of the methodology laid out here can go well beyond the curriculum assessment that I have proposed. It can look in depth at individual students' epistemological dynamics over a longer time-scale; it can uncover large scale structures or trends in student epistemologies that come from aggregating data to reach larger N groups; or it can be a tool for deep investigation of a single epistemological resource such as the knowledge-form-part-for-whole resource that showed up in my investigation of Modeling Informed Instruction.

This last track is the most enticing to me at the end of this project. All along I have been looking at large-scale methodological issues, and at the end of my work the core structure underlying behind Modeling Theories is staring back out of the data, waiting to be further investigated.

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APPENDICES

APPENDIX A

IRB LETTER

University *of* New Hampshire

Research Conduct and Compliance Services, Office of Sponsored Research
Service Building, 51 College Road, Durham, NH 03824-3585
Fax: 603-862-3564

15-Aug-2007

Meredith, Dawn C
Physics, Nesmith Hall
Durham, NH 03824

IRB #: 4047
Study: Modeling Physics in an Integrated Physics Course for Biologists
Approval Date: 14-Aug-2007

The Institutional Review Board for the Protection of Human Subjects in Research (IRB) has reviewed and approved the protocol for your study as Exempt as described in Title 45, Code of Federal Regulations (CFR), Part 46, Subsection 101(b) with the following comment(s):

1. *In the consent form, please remove "in confidence" from the last sentence of the seventh paragraph.*

Researchers who conduct studies involving human subjects have responsibilities as outlined in the attached document, *Responsibilities of Directors of Research Studies Involving Human Subjects.* (This document is also available at http://www.unh.edu/osr/compliance/irb.html.) Please read this document carefully before commencing your work involving human subjects.

Upon completion of your study, please complete the enclosed pink Exempt Study Final Report form and return it to this office along with a report of your findings.

If you have questions or concerns about your study or this approval, please feel free to contact me at 603-862-2003 or Julie.simpson@unh.edu. Please refer to the IRB # above in all correspondence related to this study. The IRB wishes you success with your research.

For the IRB,

Julie Simpson

Julie F. Simpson
Manager

cc: File
    Bolker, Jessica

APPENDIX B

TRANSCRIPT

This is the complete transcript for the interview used as exemplar data.

F2009 Materials Tension Interview :: L7G7 :: Julia

I: Um, Alright, so the first stuff I want to look at uhh... Is at the very beginning when kind of you go through and review some of the concepts, so right in the beginning of the lab. Um, so here we go.

CLIP 1 ::A-1::

I: Okay, so that's one, and in that, my first kind of question is just kind of uh, what do you get out of those kind of review questions, what's your approach to those?

Julia: Umm, well those, we're just asked to define the certain variables that they give us, so, we just kind of say something that might help us in the lab. At that point we don't really know what we're going to be doing in the lab so...

I: Okay. Um, so then, um... A little bit later, you kind of address that idea explicitly, um, where you're talking about being in the observation part of the lab. Um, we're gonna kind of piece together a couple clips here.

CLIP 2 ::A-2::

I: So, that, and then right after that...

CLIP 3 ::A-2+::

I: So, in those kind of steps where it is telling you to look at the equipment and kind of identify these initial things, um, what's kind of going through your head there? How are you approaching that part of the lab?

Julia: Well, we were told that we were gonna test the material, and so I was trying to think of a way that we could do an experiment that would test the material and not something else.

I: Okay, and so where did you get that kind of information about what the purpose was going to be? Julia: Um, that was... I think [the TA] told us about that, and that we were gonna come up- we have- we had to decide like what we were gonna be testing.

I: Okay, um... So... I guess the last thing about that is... when you are looking at you know... the equipment and you know what the purpose of the lab is going to be, um. Y'know what kind of questions might you be asking yourself there?

Julia: Um, I was just trying to think of what we might be expecting, so I know like if we got something completely off that either we're doing it wrong or we expected the wrong thing.

I: Okay. Um, so now, I want to actually move to, uh a little bit after that, so this is kind of the hands on equipment, you looked at, um, the- there's a promt asking you to make a free body diagram (Julia: mmhmm) So there was, a couple conversations that you had with your lab partner. So we're going to watch some of those, and I'll ask you about that.

CLIP 4 ::D-1::

I: Okay, so there, you and your partner are just kind of feeling out how to apply a free body diagram to the actual experiment, so can you kind of walk me through what you were thinking in that sequence?

Julia: Um, at that point I still wasn't very good with forces, so I was just trying to like, think of everything. They told us to put everything in the equation, the Fnet equals m a. So I was trying to think of where all the different parts would be included, and I was getting hung up on the fact that weight equals m a- er, m g. And I knew that gravity was acceleration, so... [shrug] I was kind of hung up on that, but I think we figured it out after.

I: Okay, um. So then, yeah, a little bit later, um, you look at, um... the- Well, here let's look at where you actually go through and work with the force sensor for a second.

CLIP 5 ::C-2::

I: Alright, so, um can you kind of tell me what was motivating that? Uh, like your little experiment there?

Julia: Um, that's like- how I was saying before like, we wanted what we expected to be somewhat what we got, so what the force probe was measuring wasn't what we expected, so we were trying to figure out why.

I: Okay, and was that tied into the free body diagram or just in general with the experimental apparatus?

Julia: Um, I think- I don't remember how we came to that, I think we were doing Fnet equals m a... but I don't remember. (I: Okay) How exactly we came to that.

I: that's fine. Um, and so, shortly after that, you and your parnter kind of go through a discussion about Newton's laws, and um working through the free body diagram some more. So I want to watch a couple clips here, and then um, ask you about that.

CLIP 6 ::D-2::

(miscue of clip)

CLIP 7 ::D-3::

I: Okay, so in those two clips, um. You guys are having like a real conversation about kind of working with newton's laws. Can you tell me a little bit about what you're trying to bring to the table there?

Julia: Um, I don't remember what they were asking us, but um, we were trying to see how it related to newton's laws. Because I know it was dealing with that in the questions, and we weren't sure what the laws were. So, we couldn't write like how they related [laugh].

I: Okay, and so, um... You did start to talk about y'know what- y'know what they were meaning right? so you said y'know "was that the counterforce... stuff from lecture..." So I'm kind of curious were you trying to- or is there a way that you see um, kind of, the laws coming into play in lab?

Julia: Yeah. (I: How do you kind of deal with that?) Um, I get it more now, we've gone over it some more, but uh, we were trying to decide if they were third law pairs, meaning like, the same types of forces acting on like the objects, or if they were different forces, just like balancing eachother. Which is the second law, and that's- like we couldn't remember which law was which so we didn't know how to like identify the forces. If they were the pairs, or if they were just balancing but different.

I: Okay. Um. So, do you remember at all in this lab, kind of what, uh, what the key things you might have gotten out of that conversation were?

Julia: Um, this, the one we just watched? (I: Yeah.) Um, well we were using that to decide what forces were acting on it. So that we knew like what we were measuring exactly, and we needed to relate that back to the material at some point, so we were trying to figure out how like the forces would relate to the material that was being used. (I: alright)

I: Alright, um. So, that's all I have on the free body diagram stuff. So, let's look at um the section of the activity where you do variable identification. Um, so... I'm gonna start out...

CLIP 8 ::B-1::

segue to CLIP 9 ::B-2::

I: Alright so, can you tell me a little bit about um... what you are trying to get at or get out of those conversations?

Julia: So, we were trying to figure out what we were going to be measuring, what would be the constant variables, versus like the- what we were changing. And um, we knew that we had to find out something about the material, in the end, that like all of our data was going to tell us something. So, we knew that the length was changing and we knew it was because of the force, and the weight we were adding. But um, we weren't sure at that point what that told us about the string, we just knew like... um whenever we added weight- or added force to the string it would stretch, and we had to measure that, and we would be um comparing it to something else to find out a property of the string that the lab was getting to.

I: alright. And, um... So, where do you kind of see that as uh, as becoming important, like when um- Well let me do this, so... one of the first things you did when you came in... uh to the lab, was have a short conversation about (how to define...)

CLIP 10 :: B-4 ::

I: So in that you're talking about um, just kind of jumping in right when you get into lab, and um, what you need from those conversations, so my question to you is kind of uh: What's your sense of the- of what you should be doing right when you get into lab, or how does that relate to the activity itself?

Julia: Um, well there's the structure, I don't know if you've looked at the books they've given us. (I: mmhmm) But, they give us a certain structure, and first we go through devining- defining the variables and figuring out like what we're going to be measuring and what we're keeping constant, what we're changing, and how that relates to each other. And um, we were just trying to figure out like what we were going to be doing, so, what we were going to be measuring and what variables we needed.

I: Okay, um. So, what kind of a role does that variable identification play for you in the- in the whole lab?

Julia: Um, well once we know our variables we can start doing the lab. And um, we can use those- so we're keeping something constant and we're changing something. We need to see how that affects another variable. And so we can start collecting the data, and after we've gotten enough data we can analyze it and see what the results show.

I: Okay, and I guess the last kind of thing in that is... So how do you figure out um, what your variables are and how they're dependent on each other and where to measure?

Julia: Um, well we usually start out by figuring out what we want to know. So, in this lab we wanted to know something about the string. And we could see that the thing changing from what we did was the length of the string. So, we would do something, which is add the weight, and the length of the string would change. So we knew that's the thing- that's the variable that we would be looking at in this lab. So we kind of formed our experiment around that variable, to get us to somewhere where we could use like the length to evaluate the properties.

I: Alright. Um, So, um... Alright, um, in the next part, I just have uh kind of some questions about using the um, the computer sensors, so, um, I'm gonna play- Y'know earlier you- we watched that clip where you used the force sensor to kind of see and check your force identification. (Julia: uh-huh) So then, um, later on... you are setting up the probe, um so we're gonna watch this then I'll ask you a little bit about that.

CLIP 11 ::C-1::

I: So, in that clip, and- um in this clip you're kind of following the instructions, um, alright, so they kind of give you a lot of um, kind of step by step, this is how to make the probe work, so um, how do you see- or how do you feel- or work with the- the probes that are connected to the computer? Do you have any um, thoughts or feelings on kind of the usefulness of those?

Julia: Um, I like them, because you can do like- you can manipulate the data a lot easier, and if you want to do one thing, then you want to switch over and do another. It's a lot easier to do it with the probe and on the computer than it is to try to figure it out by hand.

I: Okay, so what do you mean by switch over?

Julia: So, um, if I wanted to compare like the length to the mass we added, I could quickly make a graph of that using the computer. But if I wanted to compare like the length to the force, I could switch the force for the mass and have a graph of that.

I: Okay, and, so in the- in the kind of formal interaction through the- through the instructions, um... Do you feel like that's something that distances you from the- the probe, 'cause like earlier you were y'know just looking at the force from the hanger and the string, and kind of playing with it. Um, and then now, you're kind of... trying to set it up and you have to go through these instructions, so does that affect kind of your um experimental design or anything like that?

Julia: Um, No, it doesn't af- affect that. Um, it's sometimes confusing, figuring out how to do what you want to do, just because I'm not that familiar with the program. But I think once we know like how to use it and how to do what we want to do with it, it's handy.

I: okay. And, um, So... Do you find that you're still able to connect it to the physical stuff that's going on there?

Julia: Yeah. Because it lets us see rather than calcuating- like we could sit there and relate the length to the mass that we're adding and maybe calculate the force for a couple of those, but... Here it can show us exactly, like when we put this mass on it's gonna take this much force- y'know. So it lets us see some things that we uh, wouldn't necessarily see in the time period that we have.

I: Alright, and the last kind of clip with the- using the computer and the probe. Um, is a lot later on when you were uh, setting up that second variable column. Um, so I'm gonna just kind of play that quickly.

CLIP 12 ::C-3::

I: So, there you kind of question whether or not it's something that y'know you need to do manually or have the computer do it. Um, I guess the question I'd like to ask is, Do you- Do you feel like you would get anything out of the- the process of calculating out that ratio of the percentage length, or do you feel like um, y'know it's win-win using the computer?

Julia: I think it's win-win. I only questioned it because I didn't know how to do it, so I wasn't sure if the program could do it. Uh, that would be the only reason why I would do it by hand. But I think if you just look at the formula you can get a sense of what the computer is doing for you. You don't need to do it by hand.

I: Okay, so you'd say that- so that, the equation is what, um, you're gonna try to make sense out of, not the actual process (Julia: Exactly.) of ... okay.

I: So, um, the next big kind of section of the um, of the lab activity is the- so we've done the kind of initial observation, we've talked about identifying variables and getting used to the probe, um so then you do your planning stuff right? (Julia: mmhmm) So, um, first, here's a clip where your TA was talking to you. Um, and then you guys had a short conversation after that.

CLIP 13 ::Z/E-1::

I: Alright, so there, you kind of start to formulate your plan and um. Would you tell me sort of what your considerations are when you're setting up your plan?

Julia: Yeah, well he was saying um, we wanted a lot of data points. So, we wanted to know how we could use the weights um, like what increment we could use that would give us a lot of data points. 'Cause we wanted equal increments. I don't know if you have to do it that way? But, we just thought it would make it like a lot easier to see, if we had equal increments. (I: mmhmm) So, um, we wanted to divide the 900 grams by a number that would give us like a good amount of points. So, if we did 100, it would give us 9 points, but if we did 50, it would give us 18, so we chose that.

I: Okay, and so other than your TA's kind of recommendation to do a lot of data taking, um what are your motivations and thoughts on uh, writing down your plan and planning out the experiment in this way?

Julia: Um, what do you mean? Like?

I: Um, so... Wh- I guess, kind of what's the- what's the driving force for you to write down um and sketch out your plan of what you want to do for your experiment?

Julia: Um, well, we were writing it down so that we could see it, so we could have a record of what was going on. Not just like, it was on the computer. 'Cause every time we added weight like it would add to the computer, but we don't end up printing it out. We wanted to write it down so that we could have it and we could do like what we wanted with it. We had to make that- the model page, so... I don't know if that answers your question? [laughs]

I: That's fine. Okay, so after you decide on how many um, things you want, you've got a few more questions that uh, you answer with your partner, so we're gonna watch, um... clip here.

CLIP 14 ::E-2::

I: So that conversation kind of centered around units and, um, kind of choosing that ahead of time, so... What's the importance of figuring out your units and what role do they play in y'know getting through the lab and all of that?

Julia: Well, we want our units to work together. So if we had thought about it a little more we might have done kilograms because force is in kilograms meters per second squared. So that would- like when we go to um, put the data together it would work out better. Um, I don't know if it was this lab or another one, that kind of messed us up a little, because we didn't really keep track of what units we were using, but... Per- basically when we um, choose what units and what we're going to measure to we just want to make sure that um, we keep it consistent and that the significant figure is- we can actually to it an- and it's not like a guess.

I: Okay, and so what- what's the motivation there for keeping track of y'know the significant figures and, and, and the units?

Julia: That's so that we don't get into it and make a mistake later because our units don't match up. Um, I'm not sure if was this one or the other one, but we had different units for- than what we were supposed to be using, and we didn't realize that when we went to put it into the equation. And so we came out with results that didn't really make any sense to us. And um, we had to go back and figure out that it was and if we had just thought about that in the beginning and came up with the right units it wouldn't have happened.

I: Alright. So, um, that's kind of- sums up the planning there... and then um, so the next thing that you guys get into is um, the data collection stuff. So, um, what we're gonna do here is- as you guys were collecting data there were some, uh, some moments where you noticed things or, something changed and you made just some pretty short um comments, so what I'm gonna do is play through um two of them right now and then I have a couple groupings of clips that I want to then ask you about a little bit. (Julia: okay.) Um, so here's the first one.

CLIP 15 ::F-1A::

I: So that was, uh, noticing just the negative force and trying to make sense of that. And then here's another one.

CLIP 16 ::F-1B::

I: Alright, so in both of those clips you kind of have uh- Something happens, you- in the first one you notice the negative force and then in the second one your lab partner noticed that when she added mass the string had actually stretched less than she had just said. So, um, during this data collection, um, kind of what do you, um- what do you see as things that you're trying to pay attention to and trying to keep track of?

Julia: Um mainly if something is not keeping with the trend. So if we get a data point or two that just don't make sense or um like if all our data are linear and these are like way over here [motions with hand on table as if there is a data plot that is linear on the table, and some data points are far away from the linear trend]. Stuff like that we look- we keep an eye out for just to make sure we're not getting really scattered data.

I: Okay, and so what's your y'know motivation for keeping track of that stuff?

Julia: That's so that we don't get to the end and realize that we've been doing something wrong the whole time or- It's just kind of like to keep us in check. Like make sure that we're following like our original plan and not influencing it with any like, outside variables.

I: Okay, and... okay. So, uh in the next few clips I'm going to play- this was while you were um... kind of in the- in the midst of data taking there were a few things that happened. Um, so... this one involves the mass hanger swinging a little bit.

CLIP 17 ::F-2A::

I: Um, and then... uh, in this one you start to see some differences in the data trends.

CLIP 18 ::F-2B::

I: Well, so now another one where there's a little surprise.

CLIP 19 ::F-2C::

I: And then the last one for these is um, uh, a prediction that you made.

CLIP 20 ::F-2D::

I: So, in all four of these clips, um you're kind of focusing in on something, um, that you see happen, and my- my question is really, what's your intuition based on about these things? So what kind of makes them jump out at you?

Julia: Um, well I was just thinking like if I was pulling on the string, how would it work and I was thinking that it would just go straight until it got to the point where it wouldn't stretch anymore and eventually it would break, but I was a little surprised that that wasn't exactly what happened, but it did get to a point where it started to stretch less, and if we had more weight it probably would have gotten to the point where it didn't stretch anymore.

I: Okay, um, and so in the- the clip where you see the- the mass swinging what was kind of your concern there?

Julia: I was just wondering if uh the swinging would cause any extra force on it that would kind of vary our results, because the swinging wasn't constant for all of them. And um, so I wasn't sure if that would affect it or if the swinging didn't matter because it's still the same distance and the same amount of weight.

I: Okay, and so do you have any experiences that that kind of was driven by or um, y'know any thoughts on like what- what might have made that jump out at you?

Julia: Um, well, the swinging like just concerned me because it wasn't steady, but after I thought about it, um, and thinking about the distance wasn't changing and it wasn't stretching the string anymore and we didn't add anymore weight. Um, I started to think that maybe it didn't matter that it was swigning, it just had a little movement, it wasn't pulling more, so the tension wasn't more.

I: Alright. Um... And um, in the third clip there that we watched, the- I think it's that the- the data started to kind of really, um, change in direction, and you commented that you expected it to kind of go straight throughout. So, um, do you remember kind of what you were thinking about through that process of y'know you see the actual data trend different than what you expected, and what kind of a reconciliation or anything like that you go through in that?

Julia: Um, I was just thinking that if it's the same throughout that the stretch would be the same. So it would be like a linear stretch if you add weight it's going to stretch a little more. If you add the same amount of weight it would make it stretch that much more. But um, from what we've talked about in class since then it makes more sense that it would be curved and not just linear. Um, but at the time we hadn't dealt with materials yet so I was just trying to get a feel for how it would react and if I added a lot of weight like would it reach a point where it only stretches a little each time I add more weight.

I: Mmhmm. And what about in the- in the very beginning, the first couple masses that you added and then seeing y'know when you hit 200, and 250 grams, seeing the string really stretch, what um- Do you remember what kind of a reaction you had there?

Julia: Um, I think I was more surprised that it wasn't linear, that like since it was only stretching a little in the beginning and then it shot right up to stretch a lot when we added more weight. I was just expecting like if you keep adding the same amount of weight it would just keep stretching the same amount. And, the fact that it didn't kind of surprised me but-

I: Okay, and so, was that somethign that you continued to think about in the lab or did the data itself kind of convince you that that just had to be how it was?

Julia: Um, it made it more clear once we started going over it with the TA, and how to like normalize the data and how um, if you have like a certain amount of the material it will act the same, like, no matter what amount you have. You know it will act the same, it will be the same curve. And um, it made more sense as the lab went on, but at first I didn't understand why it would be that way.

I: Alright. Um, and then the last few things you noticed in the data taking were a good bit later on, it's kind of as you've got most of your data, you start to look at the pattern again, so let's watch this.

CLIP 21 ::F-3A::

I: So that was actually uh, I could have prefaced that a little better, that was as the- the string started to stretch less and you had predicted that in that earlier um clip so, um... What were you kind of thinking when you saw that the string actually started to do that?

Julia: I was thinking that if we just kept adding more weight that it would just get to a point where it didn't stretch at all anymore, so I was expecting- um, I'm not sure what weight we were at then, but I was expecting that if we added more weight like what we had, the increment between the length would just keep getting smaller until there was no change in the length anymore.

I: OKay. And did you feel validated at all when you saw the-

Julia: Yeah I felt better because my- like what I thought would happen was- like I was starting to see it. I wasn't as confused. Um, I guess it was good to see what we expected, rather than just keep seeing like what we didn't expect from the beginning when we were first planning it.

I: And, um, well, let's watch this clip, this next clip, that's kind of more of this similar idea then I'll ask you a couple more questions.

CLIP 22 ::F-3B::

I: So when you see, um, kind of the... that your- your data sampling has kind of given you enough to really show you what um, was really happening with the string, um. Can you tell me like how you're processing that information, what you're thinking about in terms of explaining back to yourself, um, what you see in the data there?

Julia: Um, yeah, it was making more sense as the lab went on, why it would be curving the way it did and um, why it wasn't just going linear, and we had discussed as a class why the curves looked that way and why they all looked the same because that's how that certain material was acting. And so um, it was making more sense that it would be acting that way no matter what length of string you had or what amount of weight, like the increments you added, um, that's the material. Like at first it would just stretch a little and then it would stretch more until it reached a point where it couldn't stretch anymore.

I: Okay, and when you say there that y'know regardless of the- the increment that you add, can you tell me a little bit more about what you're kind of thinking about there?

Julia: Yeah, so if you add, say if we added in hundred gram increments, we'd still get the same curve, we wouldn't have as many data points but if we added in like ten gram increments, there'd be a lot more data points but along that same line. So, it doesn't matter like, um, what increment we chose for the mass, it just mattered that we had enough data points to see the trend of the material.

I: Alright, and do you draw any conclusions about kind of uh, this, uh, the- how that kind of relates to what you're doing in lab and how, um, the process of lab as you go through these, kind of uh, these modeling tasks, what- does that relate to that at all for you?

Julia: Um, what do you mean? Like on all the labs? like do- how do all the labs relate or?

I: Yeah, so, how, um, y'know what you're saying there is that no matter how you um, how you perform kind of those different- how you perform the data collection itself, like with the sampling, um, that you still see that same pattern, so does that relate, um, to either other labs or just kind of this- this modeling process that you're going through in lab?

Julia: Yeah, um, it was- like it kind of shows that as long you have like a lot of data points, the specifics about how you got them, like the amount of weight you used or the increments or- um, that's all gonna follow the same trend. So like the marshmallow lab that we did, some people changed the weight and some people changed the number of marshmallows. But it still showed the same trend, and I think that relates to all of the labs, like no matter what like you chose as your increment or um, as the units of your variable say, it's all going to show the similar trend, and that's what you're looking for and that's what you have to evaluate.

I: Okay, and when you say "that's what you're looking for," is that specific to these labs or kind of in general the trend is what you're after?

Julia: In general, uh, more so, like not to get caught up on the specifics but look as it- at it as a whole. And like it's not just relating to the labs, but like many different things can relate. So like for the acceleration labs, everything has the potential to have the acceleration show those trends, it doesn't just relate to the cars we were using, so...

I: Okay, cool. Um, so after the data collection, um, then you've kind of done some preliminary kind of visual inspection. Then you get to the data representations and model construction um, section of the lab. So kind of before we watch any of those clips can you tell me like what do you- what do you see as the purpose of that part of the lab?

Julia: Um, that's kind of like a whole summary. It doesn't really include like all the prep work you do to get up to the experiment like choosing your variables and all that, but it kind of takes the data you got and summarizes it and it says it and shows it in a few different ways so that, um, maybe if one way doesn't quite make sense to you you can look at it in a different way and kind of make sense of the data you have.

I: And so y'know when you get to that point do you feel- um do you feel like your approach changes to the lab, or is it um, does it feel kind of continuous or do you kind of change gears there?

Julia: It kind of feels like a conclusion, like, "okay, this is what we've done and this is what we have, now what are we going to do with that?" And so we- that's when we like make a graph and we make sense of all of our data and we see the trends of what we were looking at, in this case, the material of the string. And um, it kind of draws all the conclusions of the questions that you've been asking like along the way.

I: Okay, so now let's get into um a few of those specific places where you've started to, um, really look at these. So, um, the first one is going to be, um, looking at, yeah, just the- getting to the data representations section, sorry.

CLIP 23 ::G-1A::

I: So, can you kind of tell me how you were approaching that, kind of naming of the column seems like y'know just a small thing, but you kind of engaged in a big conversation there so can you, walk me through your-

Julia: Um, I think that was after the discussion we had had with the class, um, about like that's how you normalize the data, and we were just trying to make sense of like, we knew it normalized the data, but we wanted to know how. And so, kind of naming the column was saying like, give a name to what we just did, and we wanted to understand that more before we just went ahead and did it.

I: Okay, and so, what's- I guess what's your kind of motivation for- for coming to that level of understanding before you um, go ahead there?

Julia: Um, 'cause if you just go ahead and you just do it, you don't really understand what you're doing, and um if you get an understanding first that makes like the next steps more clear and um it's- it clears up the confusion, so like if you take the little time then to clear up that little piece of confusion, it won't just be built upon. It'll make the rest of the lab, and what you're doing like um make more sense.

I: Alright, um... So, there's another clip, but we don't need to play it where um you go through that same kind of process and you're labelling the- your model presentation page, and so I was just gonna ask you uh, like what do you see is the value of the- of the model presentation page, how do you kind of en- engage in that?

Julia: Um, like what I was saying before with, that's like the summary of it all, so that's wrapping up like all of the loose ends and bringing together all of the different ideas and thoughts that we've had onto one sheet. And that's like representing the data we collected but really just all the different concepts that we've touched upon in the lab and all the ideas that we've touched upon and thought about.

I: Um, so, after you've kind of talked a little bit about setting those up, you start to be getting to the y'know actually um filling them out. So, here's a little bit about the data range.

CLIP 24 ::G-2A::

I: Okay, so, in that clip you guys kind of were looking at your y'know plot and starting, it seemed to um, interpret it, so can you tell me kind of what you were thinking and how you were talking to your partner about that?

Julia: Um, well we noticed the point in the lab that was kind of sharper than the other points, and um, the two ends were more curved, they weren't as linear as the middle section, and we wanted to get an accurate representation, that was the slope of the line that we were getting. We wanted to get one that accurately represented the data without including any points that might have been like, like maybe had a little error in the measurement or something. So we were just trying to choose like where we would measure our data and... so...

I: Okay, so, um, so were you connecting that to the- to the stretching of the string itself, that you had seen earlier?

Julia: Um, like choosing where we would measure on the graph? or?

I: Yeah, so, um, did you reconcile or recognize um, what uh, kind of ranges gave you that stretch?

Julia: Yeah, so we saw a trend in the middle where like when you add more weight it would stretch like the same increment. And it was pretty linear. We noticed at the ends like, it changed dramatically, so, at the upper end we would just keep adding weight but it only changed a small amount. And so we didn't really feel like that was representative of the material so we decided to exclude that to get the more representative section of the graph, to describe our material.

I: Um, then, um, a little bit later you sketch and then uh, so you sketch the plot and then you look at a couple things. So I'm gonna play a short, uh, thing about this...

CLIP 25 ::G-2B::

I: So, there um, you're kind of looking at the basic shape and can you tell me, what kind of- what do you pick up on when you are asked to make a sketch, so like what's important to you there?

Julia: So that's basically summarizing the idea that the trend is what's important and not the individual points. So, that's why we didn't have like any um measurements on our lines, we just had the variables, so the tension and the stretch. Because it wasn't the exact points that mattered it's the trend of the material that mattered.

I: Um, and then, a little bit later, after you've kind of gone through and applied the fit to the linear section and written that down, and you start to get into the verbal um- verbal representation, so let's look at that for a second.

CLIP 26 ::G-3::

I: So that was a big chunk, but a lot happened in there, so, um, do you want to kind of tell me, like what you're thinking about in that section, and kind of the value you see in that part of the lab?

Julia: Yeah, we were just trying to put into words what we were seeing in the trend, so to kind of make sense of it. It's a lot easier to like think about it, than it is to try to verbalize it. Um, so we were just trying to accurately describe the curve of the graph and um, what was happening, like the force was increasing a lot more than the length or um...

I: And, um, kind of how do you approach making sense out of that?

Julia: Um, well we just took it section by section. So, we were just trying to see like "in this chunk what's going on?" and how do we describe like what's happening. And then in the next section it's a little different so how do we describe it now.

I: Yeah, and y'know what kind of uh, I guess, um, so when you're looking at that you're interpreting the- the plot itself, so what kind of uh tools are you relying on to- to put that into words?

Julia: Um, we're just trying to bring together like all the different things that we've thought about, um, so like in the beginning what's happening with the force relative to the length. Is it a lot of force and a little length, or a little force and a lot of length. Um, we were just trying to describe that and make sense of it all, so that we could put that into words for the verbal.

I: Okay, and um, kind of the last couple things I want to ask you about, um, uh, in the last few minutes, there's a few times in this lab that you engage your TA, and ask about um, y'know getting all of the, all the parts of the activity, like um... sorry... we saw earlier when he y'know told you about um, doing all of th- y'know getting a lot of data points, but then there's another time here, um, where... you ask about w- y'know step by step recording, so here let's look at this for a second.

CLIP 27 ::Z/X-1::

I: So there's that and then just to make you watch one more of those...

CLIP 28 ::Z/X-2::

I: Okay, so um, in these types of interaction which are y'know very different then the working with the materials themselves, um, what are you y'know, what do you feel the y'know the value is of them, the lab manual, y'know, does your approach depend on y'know following the um, the activity guide, are those steps helpful, and what's kind of your motivation to- to follow it or to not follow it?

Julia: Um, I feel a lot of the steps are kind of redundant, like they'll go over variables in one section then go over them again in another section, I feel like it's kind of drawn out and to follow all the steps exactly you have to just rush through it all and try to get it done in the two hours. And I think that um, if it was a little less, like if there were less steps or if they were condensed a little more, you could get a lot more done and spend more time with the actual data then just doing a lot of the nitpicky like little steps before hand.

I: Okay, and so, um, y'know what's the, like in- in your- in this lab we saw y'know you guys jump right in in the beginning and talked about identifying variables but then y'know 15 minutes later or so you actually got to that part. And how does that kind of uh, how does that affect your approach to the lab itself?

Julia: Um, it seems a little out of order to me because like we just started right with the variables, I feel like that's where you need to start, and then formulate like your plan around than look for what variables you're interested and what variables you don't need to deal with and y'know, um. I feel like the steps are just like a little like... they kind of have a plan to them but they're a little scattered because you're doing like variables here, and then you're planning a little bit, and then you're back to variables, and then planning another part, and um. I feel like it's a little more complicated than it needs to be and if it was more simplified and less steps and it was more open ended that you could get more done, and you'd have a little more um flexibility with what you do in the lab.

I: Okay, and kind of the final thing is, how do you know that you're kind of done with the lab? So, what does it- what does it mean for you to- to feel like you've completed the lab activity?

Julia: Um, once we've answered all the questions and mainly that summary page, once we're done with that and we've gotten it all like summarized on one sheet, um it feels like we're done.

I: Okay, and at the end of that, um, y'know are there any times where you feel like you've put everything on that summary page but you don't y'know, you haven't really uh, kind of compiled it all yourself? Or you feel like um, you already understood it all without having to make that summary page one way or the other or something like that?

Julia: Um, the summary page is good, I feel like you get your understanding while you're doing the lab and then the summary just brings it all together. So like if you understand little parts along the way that kind of brings it all together. Um, but I feel like, again, like, a lot of the stuff you do before hand, um, you need to go through those steps but it's just not, you don't need to separate it out into many different little parts, you can do more things at one time. Like, if you're looking at the variables you can look at all the variables and decide what ones you're interested in and what you're going to measure out to as far as like decimal place and it doesn't need to spr- be spread out into five different steps.

I: Okay, and so you feel like once you've put all that stuff on the modeling page and um, had to take the graph and interpret it verbally, that that's kind of closed the lab for you?

Julia: Right, yeah.

I: Okay, alright, well that's everything I have to talk to you about, so.

END OF INTERVIEW